HABIT AND INTELLIGENCE.

HABIT AND INTELLIGENCE,

IN THEIR CONNEXION

WITH THE LAWS OF MATTER AND FORCE:

A SERIES OF SCIENTIFIC ESSAYS.

BY

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PREFACE.

Many of the speculations propounded in this work, as well as its entire plan, are original. It may consequently be of service to the reader to have it prefaced by a brief account of its purpose and of its leading ideas, written from the Author's point of view.

My chief purpose has been to state and to discuss what I regard as the special and characteristic principles of life. In the two chapters on the Chemistry and the Dynamics of Life, I have treated of the relation of life to ordinary matter and force: a relation which is now tolerably well understood. But the most important part of this work treats of those vital principles which belong to the inner domain of life itself, as distinguished from the principles which belong to the border-land where life comes into contact with inorganic matter and force. To that border-land belong such laws as those of nutrition and respiration: while to the inner domain of life belong the laws of organization and of mind.

In this inner domain of life, on which dynamics and chemistry have scarcely any light to throw, we find two principles which are, as I believe, co-extensive with life and peculiar to it: these are Habit and Intelligence.

I am compelled to use the word Habit in an unusually wide sense, though, as I think, a perfectly accurate one. I mean by habit, that law in virtue of which all the actions and the characters of living beings tend to repeat and to perpetuate

themselves, not only in the individual but in its offspring. This law is fundamental in both the unconscious and in the conscious life; or, to use commoner language, it is a fundamental law of life and mind. The law of the association of ideas, which is justly regarded as a fundamental law of mind, is only a case of the law of habit. I have made as full a statement as I have been able to do of the laws under which habits form, disappear, alter under altered circumstances, and vary spontaneously.

The word Intelligence scarcely needs definition, as I use it in its familiar sense. It will not be questioned by any one that intelligence is found in none but living beings; but it is not so obvious that intelligence is an attribute of all living beings, and co-extensive with life itself. When I speak of intelligence, however, I mean not only the conscious intelligence of the mind, but also the organizing intelligence which adapts the eye for seeing, the ear for hearing, and every other part of an organism for its work. The usual belief is, that the organizing intelligence and the mental intelligence are two distinct intelligences. I have stated the reasons for my belief that they are not distinct, but are two separate manifestations of the same intelligence, which is co-extensive with life, though it is for the most part unconscious, and only becomes fully conscious of itself in the brain of man.

Habit is in itself obviously an unintelligent principle. No intelligence is involved in the mere tendency to repeat an action or to perpetuate a character. But when the laws of Habit and of Intelligence have been stated, the question arises whether intelligence is an ultimate fact, incapable of being resolved into any other, or only a resultant from the laws of habit. This is by far the most important of all questions now under scientific discussion, and perhaps the most important that science can ever have to consider.

From the point of view adopted in this work, this question

divides itself into two: the one, concerning the unconscious intelligence that organizes the body; the other, concerning the conscious intelligence of mind.

The inquiry concerning the nature of the organizing intelligence involves an examination of that question of the origin of species which, since the publication of Darwin's great work on the subject, has probably attracted more interest than any other scientific question. I agree with Darwin in the belief that all species have been derived by descent with modification, probably from one, certainly from a few, original germs: and I further agree with him in attaching great importance to "natural selection among spontaneous variations" as part of the agency by which the modifications have been effected. But I altogether differ from him, in that I believe the wondrous facts of organic adaptation cannot have been produced by natural selection, or by any unintelligent agency whatever.

The latter part of the first volume is occupied with this inquiry into the origin of species and the nature of the organizing intelligence. The first part of the second volume is occupied with the parallel inquiry into the process of mental growth and development, and the nature of mental intelligence. As on the subject of organizing intelligence I have come to a conclusion which is fundamentally opposed to that of Darwin, so on this I have come to a conclusion which is fundamentally opposed to that of the dominant psychological school in this country: I mean that school which was founded, as I believe, by Hartley, and to which Mill, Bain, and Herbert Spencer belong. The characteristic point of their theory is, that they endeavour to account for the whole mental nature by the single principle of the association of ideas, or, as I call it, of mental habit. I maintain, on the contrary, that in all mental intelligence, as in organizing intelligence, there is an element not derived from habit, and not resolvable into any unintelligent force whatever.

In the chapters that follow the psychological ones, I have endeavoured to show how the science of history is capable of being elucidated by the same principles which have thrown so much light on the development of individual organisms and of organic species.

The subjects of the opening chapters are not in any obvious way connected with the laws of life. But life is a manifestation of force, and cannot be defined, or accurately thought of, except in relation to inorganic forces. For this reason I have commenced the work with some general statements on the subject of force and energy, and their relations to matter; and I have inserted a chapter on crystallization, for the purpose of showing the remarkable general contrast, with still more remarkable points of special resemblance, between the crystalline and the organic formative principles.

I have prefixed to this work an Introduction, on the subject of the historical tendency which all science is now so remarkably manifesting; and I have concluded it with three chapters containing some ideas on the classification, the history, and the logic, of the sciences.

I have throughout abstained as much as possible from technical language and technical modes of statement. It has been my aim to make the subjects treated of intelligible to any intelligent man who is willing to give the necessary attention, and to remove all difficulties except such as are inseparable from subjects which have not yet become familiar. I have endeavoured to give my authority for all important statements as to facts which are not matters of general notoriety; and when I have advanced any opinion of my own, I have advanced it as such.

In several places throughout this work, I have been brought to the borders of a region external to that which is usually regarded as the domain of science. Such subjects as the origin

of the universe, the origin of life, the nature of intelligence, and the nature and ground of the moral sense, suggest questions which, if they are to be answered at all, must be answered from data which are not to be found in the visible world. It is not from indifference to that class of questions, but rather from a conviction of their transcendent importance, that I have not entered on them in this work. I prefer to discuss them in a distinct work, which is already commenced, and which, unless a more appropriate title suggests itself to me, I purpose to call "The Scientific Bases of Faith."

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April 8, 1869.

ERRATA.

P. 78, note, *for* square, prismatic *read* square-prismatic.
P. 81, note, *for* p. 77 *read* p. 71.

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HABIT AND INTELLIGENCE,

IN THEIR CONNEXION WITH

THE LAWS OF MATTER AND FORCE.

INTRODUCTION.

IT is felt by all intelligent men, that there is a decided and even a profound difference between the intellectual tendencies of the present age and those of the last. It is felt that the point of view from which we regard the problems, both of science and of human life, is not the same as that of our forefathers of the last century. But, though this difference is universally felt, it is not easy to explain it in words, and it is quite impossible to sum it up so as to be intelligible in a single sentence.

Intellectual character of this age.

Some of the most prominent characteristics of this age, however, and those perhaps the most important of all, are in no way peculiar to it, but are an inheritance from the last century. We inherit from our ancestors of the eighteenth century the habit of rejecting authority in matters of belief, or at least of demanding that authority shall justify itself; and, with this, the resolution to go to the sources of belief and knowledge for ourselves, and the conviction that the ultimate appeal in all questions whatever, whether speculative or practical, must be neither to authority nor to custom, but to intelligence. In a word, we inherit from the eighteenth century the belief that the intellect of man has a right to rule the world. This belief belongs, at least primarily, rather to morals and politics

The rejection of authority is inherited from the last century.

Importance of this to scientific progress.

than to science, but its importance to science is nevertheless of the first magnitude. The first and most essential condition of scientific progress is the perfect independence of the intellect, and its freedom from all authority which cannot justify itself. Some sciences, in which the greatest progress has been made, have never been interfered with in their onward progress by any claims whatever on the part of authority. Such has been the case with mathematics and with chemistry. Other sciences, as astronomy, geology, and we may now add the sciences of life, of mind, and of language, have been trammelled in their infancy by the shackles of authority, and have been unable to make any great progress until these were cast away.

But in addition to this independence of authority, some of the dominant ideas of the present age in the realm of pure science have also been inherited from past centuries.

Idea of the unity and universality of natural law.

I speak of the belief that all existence is a domain of law, and that nothing is arbitrary: and of that sense of the mutual relation of all things which has passed into the current thought and speech of our time, and is expressed in such phrases as "the connexion of the sciences," and "the unity and universality of the laws of nature." These ideas, concerning the universality, the constancy, and the uniformity of natural laws, are not in any special sense characteristic of either this century or the last. They belong to science, and have been confirmed and strengthened with the progress of science. But they have taken a far stronger hold on the intellects, and I may add on the imaginations, of men in this age than they ever did before. This is a natural result of the real and great progress made by science in this age, not only in the same directions in which it was begun by former ages, but also in new directions, of which former ages only dreamed.

The most important step ever taken, in the whole history of science, towards establishing this great doctrine

Newton's law of gravitation

of the unity of law throughout nature, was Newton's discovery of the law of universal gravitation: proving that the force which binds the planets in their orbits is the same as that which causes a stone to fall to the earth:

and thereby constituting physical astronomy as one vast application of the laws of force. By this magnificent generalization, it was shown that the laws of gravitation and of motion are the same throughout celestial space: and a variety of facts which have been ascertained since Newton's time, including the wonderful discoveries of spectrum analysis, have established, with almost equal certainty, the identity of chemical laws throughout the universe.

has shown the uniformity of natural law through space.

While astronomy has shown the uniformity of natural laws throughout space, geology has shown the constancy of natural laws through time. The change which has transformed geology from a mere mass of conjectures into a true science, essentially consists in explaining geological phenomena by the same causes that we see in action at present, in the world as it is around us. The revolution in geology which is chiefly associated with the name of Lyell is an exact parallel to the revolution in astronomy which was effected by Newton. Before Newton's time, the forces which govern the celestial motions were believed to be different in kind from those of which we see the effects on the earth: Newton showed them to be the same. Before Lyell's time, the facts of geology were usually referred to imaginary "catastrophes," produced by causes of which it could only be said that they were unlike anything now in action: Lyell and his fellow-workers have shown how to account for them by the slow and continued action of those forces which we still see at work around us, in the air, in the waters, and in the volcanic fires.[1]

Geology has shown the constancy of natural law through time.

The latest of these great scientific generalizations is still in the same direction. It consists in the establishment of what is called the thermo-dynamic theory; that is to say, in proving that heat consists in molecular motion, and that the laws of heat are only a particular case of the laws of force. By this generalization, second in importance only

The thermo-dynamic theory has shown the laws of force to be true on all scales.

[1] I shall, however, have to state in the chapter on "the Motive Powers of the Universe," my reasons for believing that some of these forces, though the same in kind, acted in former times with greater intensity than they do at present.

to Newton's law of gravitation, it has been shown that the laws of force and motion apply, not to masses of matter only, but also to atoms: it has been shown that those laws are true on all scales of magnitude, from a star to an atom.

Summary. Briefly to recapitulate the substance of the last few paragraphs:—Astronomy has proved the unity of natural law through space, and geology through time; while the science of heat, and we may add those of light and electricity, have shown the same to be true on all scales.

This tendency to identify laws which at first appeared to have nothing in common, and thus to establish a wide and comprehensive unity of law, is not yet so conspicuous in the sciences of life and mind as in the inorganic sciences.

The same tendency is discernible in the sciences of life and mind.

I believe, however, that the only reason for this is the comparative backwardness of the sciences of life and mind, which is a necessary result of the greater complexity of their subject-matter. But even in them, there is a manifest tendency to break down apparent distinctions, and to establish real unity. We see this in the general abandonment of the old distinction between zoology and botany, and the merging of the two, for all philosophical purposes, in Biology, or the science of Life. We see the same in the general conviction that the science of Mind is a branch of the science of Life, or, at least, must be based on it. I hope, in this work, to do something towards proving unity of law among many of the phenomena of life and mind, which at first sight may appear to have nothing in common, by showing that the laws of Habit enter into all vital actions whatever. But the work which has already been done in astronomy by Newton and in geology by Lyell—the work, namely, of referring the most important facts of those sciences to known and intelligible laws—will not be done for the science of life, until the question of the origin of species is as much a solved problem as the problems of physical astronomy and of geology. The problems of physical astronomy have been solved by referring the planetary motions to the ordinary laws of force. The problems of geology are in process of solution by referring the facts of

geology, not to imaginary "catastrophes," but to the forces which we see at work in the world around us. And in like manner, as I believe, the question of the origin of species, which is the great question of the science of life, will be solved, and has already begun to be solved, by means of the ordinary laws of variation and development. I purpose to devote several chapters to this subject, and hope to throw on it a few rays of original light.

The question of the origin of species.

But the modern sense of the connexion and interdependence of all things goes very much deeper than the mere identification of physical laws. A most valuable habit has become general among men of mental cultivation, of regarding every subject, not as if it were alone and isolated, but in its connexion with other subjects.

Habit of regarding no subject as isolated.

Perhaps the best instance of this is one which I have already mentioned, namely, the altered way in which the questions of mental science are now regarded. Instead of beginning with the opposition of mind to matter, modern psychology begins with the connexion of the mental with the bodily nature. This modern sense of the connexion of all things is altogether opposed to the tendency of the scholastic period, which carried the love of system so far as to endeavour to map out the whole realm of knowledge into provinces separated from each other by hard and definite lines. I think we may safely affirm that if at any time the love of system were to become stronger than the love of truth, the effect would be the same. And if the attempt thus to define the province of every science by means of a rigid boundary were to be successful,—which of course is an impossible supposition,—it would condemn science to an immobility like that of the scholastic period.

Connexion of mental science with the science of life.

This is contrasted with the scholastic tendency to isolate every science.

But a still more important effect of the modern sense of the mutual connexion of all things in the bonds of law is shown in the wider, and, as I believe, truer meaning with which we are beginning to use the word *science*. For generations past, science has been usually understood to mean mathematical and physical science only: yet they have no exclusive right to the name. All knowledge is

Wider meaning given to the word science than formerly.

scientific when it is reduced to principles, and the limitation of the word to a particular class of subjects is due merely to the fact, that for the last few centuries the mathematical and physical sciences (including the science of life) are those which have been cultivated with the most success; so that in the imaginations of men they have come to dwarf all others by comparison. But this limited use of the word science was never universal; the existence of the mental and moral sciences was never forgotten; and we have now learned to use familiarly such expressions as "the science of history" and "the science of language." These are not mere chance phrases. They are indications that a time will come, and is coming, when every subject of thought which is capable of being systematically reasoned about and understood will be regarded as belonging to the domain of science, and when the use of the word science in the sense of mathematics and physics exclusively will be extinct; or, if it survive, will survive as the relic of an extinct habit of thought: like the word *mathematics* (τὰ μαθήματα), in the sense of geometry and algebra only, or *learning* in the sense of mere erudition. It is difficult to overrate the intellectual gain of the increased wideness of view, or the moral gain of the increased liberality of feeling, which may be hoped for when all students whatever have thus learned to recognise each other as fellow-workers.

Sciences of history and of language.

Benefit of this widened view of science.

I am of course aware that these remarks on the mutual relation of the various sciences are very slight and superficial; and I intend, towards the end of this work, to devote a chapter to the classification of the sciences, in which I shall state my ideas on the subject more completely and systematically.

Summary of preceding paragraphs.

In the foregoing paragraphs I have enumerated some of the results of scientific progress which have become distinguishing intellectual characteristics of the present age. They may be thus briefly summed up: In the first place, we have a profounder comprehension than any previous generation ever had, of the uniformity and constancy of natural law, not only through universal space, but also

through geological time, and on all scales of magnitude, from a star to an atom. In the second place, there is a tendency among us to regard nothing as isolated, but, on the contrary, to think of everything in its relation with the universe of which it forms a part; and, as a consequence of this, the rigid lines by which sciences were formerly separated one from the other are disappearing. And, in the third place, we are learning to extend scientific conceptions and scientific methods to many subjects, especially history and language, which formerly appeared to be outside the pale of scientific knowledge; and we are gradually learning to regard all students of every branch of knowledge as fellow-workers in science.

What is most characteristic of the scientific conceptions of this age, is the importance attached to historical methods.

But in all these we only carry forward the ideas of the last century to results of which the men of the last century scarcely dreamed; and it is, I think, universally felt that the difference between our intellectual position and theirs is something profounder than this. Our characteristic difference from them consists, as I think, in the importance which we attach to the *historical method*. History, no doubt, was written with as much ability in the eighteenth century as it has been in the nineteenth. I believe that Gibbon's great work on the "Decline and Fall of the Roman Empire" has never been subsequently equalled for vastness of research, and for lucid arrangement of very perplexing materials. But that very work is one of the best instances of the difference of which I speak, between the conceptions of the last century and of this respecting history. It consists of an admirably arranged account of events as they passed before men's eyes, with clear, if somewhat slight, sketches of the more noticeable facts of society and government. But the real problem of the history,—the reason why the Roman Empire declined from its original strength and fell before its barbarian enemies,—so far from being solved, is scarcely stated. In the present age, no historian with the tenth part of Gibbon's powers would rest satisfied with doing what Gibbon did. I do not say that he would do the work better—this depends on individual powers, not on the systems of thought which

Gibbon's "Decline and Fall of the Roman Empire."

How the same subject would be attempted now.

men learn from their contemporaries—but he would attempt more: he would not be satisfied with describing the visible effects which constitute the events of history: he would endeavour to ascend from effects to causes, and to ascertain what the causes were which produced the decline and fall of the Roman Empire.[1] This method of regarding history, not as a mere succession of events, but in the light of cause and effect, is essentially the scientific method: by it history has become scientific. It is not easy, nor is it very important, to determine how this modern and more profound conception of the problems of history grew up in men's minds. I do not think it was in any direct way due to conceptions derived from the study of physical science.

History has become scientific, and science historical.

Geology.

Thus history has become scientific, and, at the same time, science has become historical. Many scientific subjects admit of, and demand, an historical mode of treatment. This is especially true of geology, which, more than any other science, captivated the imaginations of the last generation, at least in this country. Every geological problem is an historical one; its general formula may be stated thus: From an actual state of things, to ascertain the causes which have produced it. Astronomy, also, has become in some degree an historical science. I refer, of course, to the Nebular theory, which aims, and, as I think, with a great degree of success, at giving a physical explanation of the origin of the solar system by the gradual condensation of a rotating nebula. I only mention this here as an instance, and a very remarkable one, of the tendency of science, at the present time, to occupy itself with historical questions, or questions of origin. I shall have more to say about it in the chapter on "the Motive Powers of the Universe."

The nebular theory.

The same tendency may to a great extent be asserted of the science of life, which, more than any other science, is captivating the imaginations of the present generation.

[1] This attempt has been made, I believe, with a great degree of success by Guizot, and by Mr. Finlay, the author of "The History of the Byzantine Empire."

The most interesting and important question in the science of life is, as I have already remarked, that of the Origin of Species; and this is an historical problem, or problem of origin, in exactly the same sense as the problems of geology, or that of the origin of the solar system.

The origin of species.

All problems concerning the development of living beings are, by their definition, problems of origin: this is true alike of the development of the individual and of that of the species. The problems of geology, also, as we have seen, are problems of origin. In one word, both of these two classes of problems are historical. But there is an important difference between them. The problems of vital development are not only historical but genetic.[1] By this distinction I mean that the visible facts of geology are the results of causes acting from without and unconnected with each other; but the facts of organization and vital development are the results of causes which have their seat in the nature of the living organism itself. This distinction may perhaps not be quite intelligible without further explanation. In vital development, every stage is determined by that which has gone next before it. The egg of an insect gives origin to a worm-like larva; this is transformed into a chrysalis, and the chrysalis into a winged insect resembling the parent. These changes follow each other in a fixed order, which depends, not on any external agency, but on the mysterious laws of life belonging to the species; and the same laws determine the result of the developing process—whether, for instance, its ultimate product is to be a fly or a beetle. External agencies may hinder these formative laws from coming into action; that is to say, they may destroy the life of the larva, and so prevent the development of the mature form; but they cannot modify their action, except within very narrow limits; they cannot cause one species to be hatched out of the eggs of another. I shall have to show, in the chapters on the Origin of Species, how I believe this truth to be quite reconcilable with the theory of the origin of

The problems of vital development are genetic. Explanation of this word.

History of vital development.

[1] Genetic, from *genesis*, "original production."

Contrasted with geological history.

species by a process of gradual change. In geological history, on the contrary, there is nothing in the slightest degree analogous to these fixed laws of development. There is no genetic process. Each event of the history is determined, not from within, as it is in vital development, but from without; or, in other words, each event is determined, not by the event which has gone immediately before it, but by events the cause of which has no connexion with the series under investigation. Thus, for instance, let us suppose a stratum of limestone to be deposited in a shallow sea. What formation is to come next? This is not in any way determined by the nature of the limestone; it is determined by causes which act from without, and are in no way connected with the character of the strata already deposited. If the bed of the sea continues to subside about as fast as the limestone is deposited, strata of limestone may continue to succeed each other for an indefinite time. If, on the contrary, it is raised so as to convert the limestone stratum into dry land, an indefinite time may pass without any deposit whatever being formed over it. If the limestone continues to be covered by a shallow sea, while a change of the levels in a neighbouring continent causes a great and muddy river to flow into that sea, the mud will form a stratum lying over the limestone, and of a mineral character totally different from it: and if, what is a very probable occurrence, great spaces of very shallow water are kept free from mud by means of dense borders of aquatic vegetation, then, if the conditions of climate are favourable, these spaces will themselves be overgrown with vegetation, which, dying, will produce beds of a peaty substance: and subsequent geological changes may transform this into coal. And all these strata may be mechanically broken up and contorted by volcanic action, while at the same time they are chemically metamorphosed by the volcanic heat.

These examples will, I think, make my meaning clear when I speak of the difference between a genetic process and a simply historical one. A genetic process may be

defined as one which is governed by an internal law of development.

Now, the most characteristic studies, and the most characteristic methods, of this age, are the genetic ones. The science of life is studied genetically: the laws of the development of individual organisms are among the most important of the results yet attained by the science, and the development of species is the most important of its problems. History is studied genetically: the historian does not think he has done his work unless he can trace the process by which one set of events, or one state of things among mankind, has given origin to another. The same is true of what may be called the secondary historical studies, such as the history of art and literature; and it is eminently true of the history of law, which study may be said without exaggeration to have attained to the rank of a science in the hands of Mr. Maine, whose work on Ancient Law shows an amount of research which is quite comparable to that of Gibbon, while at the same time it is illuminated by such a conception of true historical method as was never attained by any historian of the eighteenth century.

Genetic studies and methods are characteristic of this age.

Science of life.

History.

History of law.

The same is true of the science of language. The science of language is the history of language. Every language has been formed by a spontaneous genetic process, and the problems of the science consist in ascertaining the laws of the process. Little is known of the first origin of language, though it is not, perhaps, a totally insoluble mystery; but very much has been done towards determining the laws according to which one language is derived from another; and it does not derogate from the value of our knowledge of historical facts and genetic laws, if the first origin of the subject of the history is unknown.

Science of language.

It has become an axiom in the science of life that "development is the criterion of morphology;" which may be thus paraphrased, in untechnical language: "In order to know what a thing really is, we must know the process of its origin." This law is subject to some remarkable

Development is the criterion of morphology.

exceptions, of which I shall have to speak when I come to the subject of the Origin of Species; but I shall endeavour to show that they are more apparent than real: of its general truth there is no doubt whatever, and no naturalist would regard the classification of any newly discovered form as more than merely provisional, until he had ascertained the mode of its development.

To know what a thing is, we must know its origin.

Now, this axiom, that development is the criterion of morphology, or that, in order to know what a thing really is, we must know the process of its origin,—this axiom, I say, though it was first stated of living beings, is really of much wider application; it is applicable to all things whatever which are produced by a process of development, according to an internal genetic law. It is, for instance, impossible—impossible, I mean, in the sense of involving a contradiction—really to understand a work of art, without understanding the mind of the artist who produced it, at least sufficiently to perceive his meaning and intention: and this is identical with a rudimentary knowledge of the mental process by which his work has been produced. This is perhaps the clearest and best instance that can be quoted from among the studies that arise out of human history and the productions of the human mind; but the same is true, and is now generally recognised as true, of political institutions. No institution, or, to use a wider expression, no state of human society, can be really understood unless its origin and its history are known; and it is possible for institutions to be exactly the same in form and yet totally unlike in reality, if they are different in origin. Constitutional government, for instance, may be one thing in a country where it has spontaneously grown, and may be a totally different thing in another country where its forms have been exactly imitated, but where it has no historical root.

Wide applicability of this axiom.

Artistic criticism.

Political institutions.

These truths are now commonplaces: the saying that "constitutions are not made, but grow," has become a proverb. The fact that this class of truths has become commonplace among us, constitutes, as I think, the intellectual peculiarity of the present century, and, I will

The recognition of this principle is

add, its superiority to the last. We have learned to apply historical and genetic methods wherever they are applicable: and the importance of this is very great, not only in the study of science and of history, but in its practical application to human life. To use expressions which though familiar and hackneyed have a profound meaning, it has made political thought at once more conservative and more liberal.

what is most characteristic of this age.

The increased importance which we have learned to attach to historical methods has made political thought more conservative; for it is impossible that a student of history should despise the past. He may be a believer in indefinite progress; he may believe that the present is better than the past, and that the future will be better than the present. But he must recognise the truth, that no man or nation can "break with the past;"[1] that the present is the result and outgrowth of the past, and that the future will be the result and outgrowth of the present; and, however lightly he may esteem all that has been actually attained by the past and by the present, he must value them for the wealth of data and materials which they contain for the future. He may be boldly constructive; but he must be conservative, inasmuch as he cannot be destructive. The habit of mind which is produced by the historical and genetic study of the deeds and thoughts of men is opposed alike to revolutionary destruction and to what may be called revolutionary construction: I mean the direct application to practice of political and social theories deduced from *à priori* data, and independently of historical experience, according to the method which was characteristic of the period of the French Revolution—or perhaps we ought rather to say, of the period which prepared for that great revolution, and led up to it. The vast change which has come over the thoughts of cultivated men on this class of subjects may be gauged by comparing Bentham with Stuart Mill: especially because, notwith-

Conservatism.

Bentham and Stuart Mill.

[1] De Tocqueville, in his "France before the Revolution," has completely disproved the current notion that France, in the great Revolution, succeeded in breaking with the past.

standing this great difference, Stuart Mill regards himself as fundamentally belonging to the same school of thought with Bentham. Between Bentham's treatment of political questions and Mill's, there is all the contrast between revolutionary construction and construction on an historical basis.[1] In the present (1868) state of Europe, and especially of England, it is impossible to predict how many experiments in revolutionary construction may be tried by an uneducated democracy; but we are safe in asserting that the influence of the cultivated classes, for the present and for an indefinite time to come, has been secured on the side of an historical way of regarding all political questions, and against revolutionary construction as well as revolutionary destruction.

Liberalism.

At the same time, the new historical style of thought tends to make men more tolerant and more liberal. Historical and genetic modes of studying the thoughts and the actions of those who have gone before us have necessarily the effect of producing the power, or if not the power at least the desire, to appreciate the objects of study. We no longer think it enough to judge, however justly, of deeds, or of laws, or of works of art. We endeavour to account for them; to see them not only with our own eyes, but with the eyes of their authors; to see them, as it were, not only from without, but from within. This appreciative sympathy with man is at the very root of all that is best in that political and moral creed which is rather vaguely called Liberalism; and it has, I believe, acted powerfully, though in part unconsciously, in producing the characteristically modern sense of the sacredness of mental freedom, and of the sinfulness of all persecution of opinion, whether the opinion be religious or any other. For we have learned that belief is utterly worthless, except when it is the product of free conviction. We have learned that what is in form the same belief, or the same creed, may be one thing if it is the result of free conviction, and a totally different thing if it is the result

Toleration of all opinions.

[1] See the Essays on Bentham and on Coleridge in Stuart Mill's Dissertations and Discussions.

of mere habit, or if it is imposed by external power; that it may be more precious than life in the one case, and more worthless than "salt which has lost its savour" in the other. We have also learned to apply the same principles to politics, and to recognise the truth that what are in form the same institutions may be in reality quite different if they are imposed from without, from what they would be if they were the spontaneous product of national life. And in close connexion with this is the modern sense of the *educative* value of political institutions and political history; in other words, their value, not only in the transaction of national business and in promoting outward national prosperity, but also in their influence on national character.

Conclusion.

To conclude, I have in this Introduction briefly endeavoured to show that the chief and the most distinctive intellectual characteristic of this age consists in the prominence given to historical and genetic methods of research, which have made history scientific and science historical: whence has arisen the conviction that we cannot really understand anything unless we know its origin; and whence we have also learned a more appreciative style of artistic and moral criticism, a deeper distrust, dislike, and dread of revolutionary methods, and a more intelligent and profound love of both mental and political freedom.

CHAPTER I.

MATTER AND ENERGY.

IN this series of Essays I intend to proceed, according to the law both of nature and of thought, from the simple to the complex. Consequently, I shall treat of the laws of Matter before those of Life; and, in treating of the laws of Matter, I shall treat of those which are common to all matter, and to matter in all its actions, before the special laws of chemistry and crystallization.

It is not my purpose to write a regular treatise on elementary dynamics. In this and the following chapters I only intend to give a statement of some of the most important results of modern dynamical science, in a form that shall be at once theoretically complete and suitable for future reference. I shall employ as few mathematical terms as possible; but I fear it will be impossible to make the subject perfectly intelligible except to those who are acquainted with the fundamental conceptions of mathematics.

Four laws of conservation.

There are in nature four, and only four, laws of conservation which we can assert to be absolutely and without exception true. These are the laws of the Conservation of Matter, of Momentum, of Rotation, and of Energy. These must be explained *seriatim*.

Conservation of matter.

I. THE CONSERVATION OF MATTER.—*Matter can be neither produced nor destroyed by any process whatever.* This truth has been long known, and is familiar; but it is very far

from self-evident. When wood or coal, for instance, is burned, it appears to be destroyed; but we know that the carbon which disappears combines with the oxygen of the air to form carbonic acid gas.

Conservation of momentum.

II. THE CONSERVATION OF MOMENTUM.—*The total momentum of any body or system of bodies is unchangeable by any mutual action of its parts;* or, in other words, *the motion of the centre of gravity of any body or system of bodies is unchangeable by any mutual action of its parts.* That is to say, if the centre of gravity of any system of bodies—as, for instance, the solar system—is at rest, no mutual action of the bodies composing it can set it in motion; and if it is in motion, no mutual action of the bodies composing it can bring it to rest; nor can any such action alter the motion of the centre of gravity, either in direction or in velocity.

The case of an animal or a railway engine that moves itself, is no exception to this law; for it is set in motion, not by the action of its parts *on each other*, but by the action of the whole *on the ground* which serves it as a fulcrum.

Conservation of rotation.

III. THE CONSERVATION OF ROTATION.—*The total rotation of any body or system of bodies is unchangeable by any mutual action of its parts.* That is to say, if any system of bodies has no total rotation, no mutual action of the bodies composing it can cause it to rotate; and if it is rotating, no mutual action of the bodies composing it can bring it to rest; nor can any such action alter the total amount of rotatory motion, either in direction or in velocity.

The case of a rotatory steam-engine, or a horse in a mill, is no exception to this law; for they are set in motion, not by the action of their parts on each other, but by the action of the whole on the framework or the ground that serves as a fulcrum.

Amount of rotation, how estimated.

The total amount of rotation is thus estimated. Let a line of indefinite length be drawn as an axis. It may be drawn anywhere, and in any direction; it

may be drawn either through, or outside of, the system of bodies in question; but for the purpose of forming a clear mental representation of the subject, let us suppose it drawn through the centre of gravity of the system of bodies, and at right angles to the principal plane of rotation. (For the solar system, this is nearly the same as drawing it in the line of the sun's axis of rotation.) From this axis, and at right angles to it, let a radius vector be drawn to every indefinitely small part of the bodies, all such parts being supposed of equal mass. Then *the algebraic sum of the products of the radii vectores into the tangential components of the velocities will be a constant quantity.* Or, to state the law in a slightly different form: *the algebraic sum of the areas swept over by the radii vectores will be equal for equal times.*

Conservation of areas, a synonymous term with conservation of rotation.

In allusion to this latter mode of statement, the law of the Conservation of Rotation is often called the law of the Conservation of Areas. What is still called Kepler's second law, namely, that the radius vector of every planet sweeps over equal areas in equal times, is the best known instance of the law of the conservation of rotation or of areas. In consequence of the perturbations which the mutual attractions of the planets produce in each other's motions, Kepler's Second Law is not absolutely true of any one planet; but it would be so, if the solar system consisted only of the sun and a single planet.

Conservation of energy.

IV. THE CONSERVATION OF ENERGY.—*Energy,* like Matter, *can be neither produced nor destroyed by any process whatever.* Or, in other words: *Whatever quantity of energy has been expended in doing work, reappears as energy.*

Transformation of energy.

The conservation of energy, like the conservation of matter, is contrary to appearance. But energy, like matter, when it appears to be destroyed is really transformed. For instance, when a railway train is stopped by the action of the break, or when a cannon-ball sticks fast in a bank of earth, the energy of motion which has disappeared is transformed into heat. The heat that is produced by mechanical action, such as friction or collision, is not a

mere concomitant of the mechanical action, as was formerly believed; it is energy of motion, which, as we have every reason to believe, has been transferred from the mass to the molecules.

The conservation of energy was formerly, and is frequently still, called the conservation of force. But, as I shall have to explain, the word force has another meaning; and Professor Rankine has proposed the word energy in this sense.

In order to explain what is meant by the conservation of energy, I must begin by defining the words momentum, force, energy, and work.

The momentum of a moving body is the product of its mass into its velocity. Definitions of Momentum,

Force is that which produces motion. Equal forces are those which, when acting through equal times, produce equal momenta. It follows from this that equal forces, acting in opposite directions, neutralize each other; as, for instance, two weights on the opposite ends of a lever which balance each other, so as to prevent either from descending. Force,

Energy is that which does work. Equal quantities of energy are those which are capable of doing equal quantities of work: or, in other words, equal quantities of energy are those which are capable of overcoming equal resistances through equal spaces. When for instance a weight is raised, a quantity of energy is expended and transformed, proportionate to the product of the weight into the height through which it has been raised. Energy,

Work is thus correlative with energy, and work may be defined as *resistance overcome.* and Work.

Energy is not the same as Force. All energy has its origin in force, but force cannot pass into energy unless it is at liberty to act. Thus, gravity is a force, but no energy is due to it unless it has space through which it can act by causing bodies to fall: and *the quantity of energy is proportionate to the gravitative force, multiplied into the space through which that force acts.* For instance: the weight, or gravitative force, of the water of the ocean causes it to Measure of energy.

press on its bed with a pressure proportionate to the depth; but no energy is due to this pressure, because there is no space through which the water can fall. But to the position of the water in a mill-pond a quantity of energy is due, proportionate to the weight of the water multiplied into the height through which it may be allowed to fall.

Potential and actual energy.

Energy which is thus due to the possible action of a primary force[1] that is not actually in action, is called potential energy. When energy ceases to be potential, it becomes actual. The potential energy of a raised weight is proportionate, as I have just explained, to its mass multiplied into the height through which it is *capable of falling;* the actual energy of a moving body is proportionate to its mass multiplied into the height through which it *must have fallen* in order to acquire its velocity.

Their mutual transformation in the motion of a pendulum.

Potential and actual energy are in constant process of transformation, the one into the other. The simplest case of this is the oscillation of a pendulum. During the descent of the pendulum-bob, a portion of energy proportionate to the vertical height through which it descends is transformed into the actual energy, or energy of motion, due to its velocity at the lowest point of its stroke; and when the pendulum-bob rises to its former height on the opposite side, this actual energy is transformed back into potential energy again. Supposing no energy to be wasted by friction, the pendulum-bob will always rise to exactly the same height at the ends of the stroke, and will always attain to exactly the same velocity in the middle: as required by the law of the conservation of energy, no energy will be either lost or gained. This condition of the total absence of friction is not perfectly attainable in our experiments, but we can make a very near approximation to it. As already stated, the energy wasted in friction is not destroyed, but transformed into heat. This transformation of energy thus effected in the oscillation of the pendulum is a simple type on a small scale of what is constantly going on in endless complexity and on the vastest scale throughout the entire universe.

[1] For the meaning of the expression *primary force* see p. 32.

Energy may be stored: instance of the hydraulic accumulator.

Energy, like Matter, is measurable by quantity;[1] and, like matter, energy is capable of being stored. A mill-pond is a means of storing energy; and a still better instance, though exactly the same in principle, is Sir William Armstrong's hydraulic accumulator. This is a contrivance for enabling a small steam-engine or other source of motive power to do very heavy work for a short period of time. It consists of a forcing-pump, through the action of which, by hydraulic pressure, the motive power of the steam-engine raises a very heavy weight. An amount of potential energy, proportionate to the weight multiplied into the height through which it is raised, is thus accumulated; and when it is desired to give out energy and do work, this is done by letting the weight descend and using its pressure as motive power. The steam-engine is able to raise the weight but slowly, but the weight is able to descend rapidly, so that the potential energy which is stored up through a comparatively long time may be given out in a short time, and employed in work that requires a great expenditure of energy in a short time, as, for instance, in raising great weights.

Perpetual motion: in what sense impossible.

From the law that energy can be neither produced nor destroyed, follows, to use the common expression, the *impossibility of a perpetual motion.* But this is not a good expression: in any obvious meaning of the words it would be much nearer the truth to say that the law that energy cannot be destroyed makes perpetual motion *necessary;* and this is rigidly true if, as we cannot doubt, heat is a form of motion. What is meant, however, by the impossibility of a perpetual motion, is the *impossibility of an inexhaustible source of energy.* It is impossible, for

[1] It may be thought that whatever is measurable at all must be measurable by quantity. This, however, is not the case. Heat, for instance, is measurable by quantity; equal quantities of heat will melt equal quantities of ice. But temperature is measurable, not by quantity, but by degree: *quantity of temperature* would be an unmeaning expression. So of force; equal forces will balance, and will be balanced by, equal weights. We say, for instance, that the force of atmospheric pressure, as measured by the height of the column of mercury that balances it in the barometer, varies from hour to hour; but the *quantity* of this force would be an unmeaning expression.

instance, to construct a machine that can do work without parting with energy; and when the energy is all parted with, any machine whatever must necessarily cease to do any more work unless a fresh supply of energy is brought in from without. It is impossible to make a water-mill work without a constantly renewed supply of water, or to make a steam-engine work without a constantly renewed supply of fuel. Every one who understands mechanics knows that any such inexhaustible source of energy is impossible by means of merely mechanical arrangements; but it is equally true, though not perhaps quite so evident, that it is impossible by means of any arrangement of thermal, electric, or chemical forces.

NOTE.

FORCE AND ENERGY.

In the present note I purpose to add some further explanations and illustrations of the relation between Force and Energy, in order to assist the formation of clear conceptions on a subject that lies at the very root of physical science, and yet is often insufficiently understood.

Faraday's question,

Some years ago, the greatest purely experimental philosopher then living, and perhaps the greatest that has ever lived—I mean, of course, Michael Faraday—surprised not only scientific men but thinking and reading men generally, with the question:

as to the law of conservation.

How can the law of the Conservation of Force, according to which force is *invariable*, be reconciled with the law that the force of gravity *varies* inversely as the square of the distance?

Answer.

This question really perplexed Faraday's mind. But the difficulty arises from a purely verbal confusion. Speak of the Conservation of Energy instead of the Conservation of Force, and the apparent contradiction disappears. There is no contradiction between the law of the conservation of *energy*, and the law that gravitative *force* varies in the ratio of the inverse square of the distance.

The same distinction solves another question that perplexed Faraday. Gravitation is a force; electricity is a force; all forces whatever are correlated; what is the special correlation between these two? Faraday devised experiments in order to discover some such special correlation, but did not obtain any result.

Faraday's question as to gravity and electricity.

The answer to the question is, however, very simple, and easy to illustrate by experiment. Gravity is a *force*, and electricity is a *form of energy:* the force of gravity may produce the energy of motion of a falling body, and part of that energy of motion may be transformed into the energy of electricity. If the weight of falling water works a water-mill, and this works an electrical machine and produces electricity from it, there is a perfect experimental illustration of the relation between gravitation and electricity; for the electricity, like the heat, which is produced by friction, is not a mere concomitant of the friction; it is a part of the energy of motion, which has been transformed.

Answer.

The same verbal ambiguity was at the root of the controversy, now long ago settled, as to the measure of the force of a moving body;—whether the force was proportionate to the mass multiplied simply into the velocity, or to the mass multiplied into the square of the velocity. All are now agreed that the *energy of motion*, to which the power of doing work is due, is proportionate to the mass multiplied into the square of the velocity. For instance: supposing the mass, or weight, of a projectile to be given, its power of penetrating is proportionate to the square of the velocity. But the *force* of a moving body is proportionate to the mass multiplied simply into the velocity: in other words, to its momentum. The proof of the last statement is this. As already stated, equal *forces* acting in opposite directions neutralize each other. Now, it is found by experiment as well as by theory, that equal *momenta* in opposite directions neutralize each other; that is to say, two bodies coming into collision with equal momenta in opposite directions (supposing of course that they are of lead or some other inelastic substance, so as not to rebound) will destroy each other's momenta and bring each other to rest.

Controversy as to the measure of Force.

Energy of motion

and momentum.

In such a case, the energy of motion that disappears is of course transformed into heat.

It follows from the statements given above as to the measures of momentum and of energy of motion, that if two bodies are in motion whereof one has a hundred times the velocity of the

other and only a hundredth of its mass, their momenta will be equal; but the smaller one will have a hundred times as much energy of motion as the larger. For instance: suppose a cannon to be placed on a railway smooth enough to enable it to recoil without any sensible friction; and suppose a projectile of one hundredth of the weight of the cannon to be fired from it, the law of the conservation of momentum makes it necessary that the position of the common centre of gravity of the cannon and the projectile should be unchanged; consequently the velocity of each will be inversely as its mass, and the cannon will recoil with a velocity equal to a hundredth of that of the projectile. Their momenta will consequently be equal; but the energy of motion of the projectile will be a hundred times that of the cannon.

Their difference illustrated.

Of course the quantity of heat, or of any other form of energy that is produced when motion disappears, is due, not to the momentum, but to the energy of motion; not to the velocity simply, but to the square of the velocity.

CHAPTER II.

TRANSFORMATIONS OF ENERGY.

AS already stated, the energy of motion of a moving body is due to its mass multiplied into the height from which it must have fallen in order to acquire its velocity.[1] And also, its energy of motion is proportionate to its mass multiplied into the square of its velocity. Energy of motion is thus definitely measurable by quantity.

Energy of motion,

Heat is also definitely measurable by quantity. Equal quantities of heat are those which equally increase the temperature of equal quantities of the same substance. For instance: equal quantities of heat will raise the temperature of equal quantities of water by one degree of the thermometer.

and heat, are measurable by quantity. Measure of heat.

Now, it is found by experiment that *equal quantities of energy of motion are capable of transformation into equal quantities of heat;* and, conversely, equal quantities of heat are capable of transformation into equal quantities of energy of motion. This is called the law of the dynamical equivalent of heat. Its numerical statement is, that the energy which is due to the descent of one pound of weight of any substance whatever through 772 feet of height is capable of transformation into so much heat as will raise the temperature of one pound of water by 1° Fahr.[2] This,

Dynamical equivalent of heat.

[1] See page 20.

[2] Tyndall on Heat as a Mode of Motion, p. 40. It would take a fall through 1,390 feet to raise the temperature of a pound of water by 1° Centigrade.

as might be expected, is alike true, whatever be the process by which the transformation of the energy of motion into the heat is effected: whether it is by collision, as when a projectile flashes fire against the target;[1] or by friction, which may perhaps be regarded as consisting of an infinite number of molecular collisions; or, as in one of the experiments by which Professor Joule ascertained this law, by transforming energy of motion into electricity, and this into heat; or by the compression of air.

It is scarcely necessary to say, that when all the energy of motion of a moving body is transformed into heat, the body ceases to move.

Heat is molecular motion.

This fact, that whatever quantity of energy of motion disappears is represented by an equivalent quantity of heat, makes it highly probable that heat is really motion, the motion of the molecules of the heated substance; so that the *transformation* of energy of motion into heat is really the *transfer* of the energy of motion from the *mass* of the body that ceases to move to the *molecules* of the bodies that become heated. In a word, *heat is molecular motion.* I do not say that the facts already mentioned are sufficient to prove this: I admit that they only suggest it. But this theory is confirmed by all that we have learned of the action of gases under pressure; and the dynamical theory of heat is now as well established as the undulatory theory of light.

All matter is perfectly elastic.

I may here remark, though it is a digression, that the fact of the apparently lost energy of motion being transformed into heat, or molecular motion, proves the very important and previously unknown truth, that *all matter is perfectly elastic.* If two balls of a highly elastic substance, such as ivory, come into collision, they rebound with great force, and very little of their energy of motion disappears. But if two balls of lead, or of any other almost inelastic substance, come into collision, they rebound with

[1] "Mr. Fairbairn informs me that in the experiments at Shoeburyness it is a common thing to see a flash of light, even in broad day, when the ball strikes the target." (Tyndall on Heat as a Mode of Motion, p. 437.)

very little force, and nearly all their energy of motion disappears. We now, however, know that the energy of motion which is lost by the masses is transferred to the molecules, being transformed into heat; so that the elasticity in which the masses are deficient is shown to belong to the molecules. Thus, what appears to be inelasticity is really a form of elasticity.

Motion transformed into electricity.

When energy of motion disappears, it is generally transformed into heat, but under special circumstances it is transformed into electricity. This is done by the common electrical machine, in which, by a suitable arrangement, a large part of the energy of motion that is usually transformed by friction into heat is transformed into electricity instead. The law on this subject appears to be, that similar substances rubbing against each other produce heat, but dissimilar ones produce electricity; and the more unlike the substances are to each other, the more of the energy of motion that disappears is transformed into electricity, and the less into heat.[1]

In the electrical machine, artificial means are used to retain the electricity when it is produced. But when these are not used, the electricity nearly always escapes as soon as produced, and, in escaping, is transformed into heat. We may consequently lay it down as a law which is practically true throughout nature, that when energy of motion seems to be lost, it is really transformed into heat.

Energy of motion is also transformed into electricity by a totally different process in the magneto-electric machine.

The nature of electricity is not nearly so well understood as that of heat and light. I state some experiments and reasonings bearing on the subject in a note to Chapter III.

Quantitative equivalence of all forms of energy.

Equal quantities of energy of motion, as already stated, are capable of transformation into equal quantities of heat; and equal quantities of energy of motion are capable of transformation also into equal quantities of electric energy.[2] Equal quantities of electric energy and of heat

[1] Grove on the Correlation of Physical Forces.

[2] I say that equal quantities of heat or of energy of motion are capable of transformation into equal quantities, not of *electricity*, but of *electric*

are also capable of transformation the one into the other. This relation of *quantitative equivalence* must indeed necessarily exist between all forms of energy, in consequence of the law of the conservation of energy, by which energy is unalterable in quantity through all its transformations: it may be transformed, but its quantity can be neither increased nor diminished.

Radiation of heat.

One of the most remarkable properties of heat is its property of transferring itself from one body to another, across vacant space, by radiation. But when heat assumes the radiant form, as it does, for instance, when on its way from the sun to the earth, it obeys laws totally different from those which are properly the laws of heat—it obeys laws which are, so far as experiment can inform us, perfectly identical with those of light—it becomes capable of reflection, refraction, and polarization. Radiant heat is thus a distinct form of energy from heat of temperature, or what is properly called heat; while, on the other hand, it differs from light only as two differently coloured rays of light differ from each other. And the same is true of the invisible chemical rays of the solar spectrum, or what have been called the actinic rays; they differ from light or from radiant heat only as two differently coloured rays of light differ from

Radiant heat, light, and the actinic rays.

energy; for the quantity of heat, or of any other form of energy into which the electricity of an electrised body is capable of being transformed, is not simply proportional to what electricians call the *quantity* of the electricity wherewith it is charged, but to the *quantity* of the electricity multiplied into its *tension:* or, what comes to the same thing, supposing the extent of electrised surface to be given, the quantity of heat into which the electricity is capable of being transformed is proportional, not to the quantity, but to the square of the quantity. This may be compared with the law that, supposing the mass of a moving body to be given, the energy due to its motion is proportionate, not to the velocity, but to the square of the velocity. (See p. 24.)

The definition of electric intensity and of quantity of electricity is, that if an electrised ball of metal is brought into contact with an unelectrised one of the same size, the electricity will spread over both; and when it has so spread, its *quantity* is said to be unchanged, but its *intensity* reduced to one-half. In this diminution of intensity there is a transformation of energy into heat. (See De La Rive's Electricity, English translation, vol. ii. p. 219, *et seq.*)

each other.[1] Light, radiant heat, and the actinic rays, all beyond any reasonable doubt consist of vibrations in a medium that fills all space. They are consequently to be classed as one and the same form of energy, which I intend in future to call *radiance*. The fact that only some of the rays of the sun's radiance are luminous depends not so much on their own nature as on the properties of the nervous apparatus by which we see; and it is not at all improbable that to some animals rays may be luminous—that is to say, may give the sensation of light—which are obscure to us.[2]

classed together as radiance.

When radiance is absorbed, it is transformed back into heat; as, for instance, when the sun's radiance warms an object on which it falls. Radiation is the transformation of heat into radiance; absorption is the transformation of radiance back into heat.

Absorption of radiance.

If radiance is a form of energy, concerning which there can be no doubt whatever, every ray must have some energy. The energy of the luminous and actinic rays, however, when separated from the obscure ones, is very small, as shown by their very small heating power. The rays of the moon are usually believed to have no heating power at all, but Professor Piazzi Smith found that the heat of the moonbeams on the Peak of Teneriffe, as measured by the thermo-electric multiplier, are equal in heating power to a candle at a distance of twenty-six feet.[3]

Heating power of moonbeams.

I have now enumerated the principal kinds of actual energy, namely, Energy of Motion, Heat, Electricity, and

[1] This is not quite accurate, for all rays are heating rays: if it were not so, there would be radiance incapable of transformation into heat, and we know that all energy is capable of transformation into heat. But the maxima of heating power, of illuminating power, and of chemical power, occur in different rays.

[2] It has been suggested that the eyes of cats and other nocturnal animals are more sensitive than ours to the highly refrangible rays which abound in twilight.

[3] Piazzi Smith's Teneriffe, p. 212. Piazzi Smith found that when the moon was at an altitude of about 42° and the weather perfectly serene, its heating power was equal to about a third of that of a candle fifteen feet off. By the law of the inverse square, the heating power of a candle at fifteen feet is three times what it is at twenty-six feet.

Radiance; and shall proceed to enumerate their principal modes of transformation.

Transformation of motion into heat,

I. Motion is directly transformed into heat by collision and friction, and also by the compression of air or any other gas or vapour.

and the converse:

Conversely, heat is transformed into motion by the expansion of gases and vapours under pressure, as in the steam-engine. It is experimentally proved that when any gas or vapour expands into vacant space, so as to do no work in expanding, its temperature is not altered by expanding; but when it expands in such a way as to do work by expanding (as steam does in the cylinder of a steam-engine), its temperature falls; and the heat that has disappeared is the equivalent of the work done.

Motion into electricity,

II. Motion is transformed into electricity by the common electric machine, and also by the magneto-electric machine.

and the converse:

Conversely, the energy of electricity is transformed into that of motion, when a body is moved by electric attraction or repulsion.

Electricity into heat,

III. Electricity is transformed into heat, when it is discharged under such circumstances as to prevent work from being done in any other way. This takes place in the formation of the electric spark.

and the converse:

Conversely, heat is transformed into electricity, and an electric current is produced, when two substances that conduct heat unequally are placed in contact, and heat applied at the point of contact. Such currents are called thermo-electric currents.

Heat into radiance, and the converse.

IV. Heat is transformed into radiance by radiation.

And, conversely, radiance is transformed into heat by absorption.

We have seen that by the law of the conservation of energy, the energy that does work always reappears as energy. This is self-evident when the resistance overcome in doing the work consists in raising a weight; the energy reappears as the potential energy due to the raised weight, and is ready to be converted into actual energy again when the weight falls. When the resistance over-

come consists in friction, we now know that the work done is represented by heat or electricity. But when the work done is of such a nature as to alter the state of the body on which work is done, as for instance in sawing wood or grinding corn, it might be supposed that the energy that has done the work is represented by the work done, and will not reappear as energy. This, however, is not the case; it is transformed into heat or electricity, just as when the work done consists simply in overcoming friction.

No exception to the reappearance of the energy that has done work.

In speaking of the potential energy of gravitation, I have remarked that a force cannot produce energy, if, like the pressure of the ocean on its bed, it is so placed that it cannot cause motion. But the force that is overcome in sawing wood or grinding corn—namely, the force of solid cohesion—is a force that cannot produce energy, not for want of room to act, but because it is not its nature to do so. It is *mere* resistance; and it would be an improvement in our scientific language if the word *force* were confined to forces that can produce motion, and the word *strength* always applied to forces of mere resistance.

Forces that cannot produce energy.

Strength is measured by the force required to overcome it: the strength of materials, for instance, is measured by the weights needed to break or crush the materials.

Measure of strength.

CHAPTER III.

STATIC AND KINETIC ENERGY.

I HAVE defined potential energy as "energy due to the possible action of a primary force that is not actually in action."[1]

Primary forces.

By primary forces I mean forces which do not originate in any other forces, but are to be referred directly to the laws of nature. Gravity and chemical affinity are primary forces: matter has been created with them. But the attractive and repulsive forces of electricity and magnetism are not primary forces, because the electrised and magnetised states of matter are not parts of its original constitution. Matter may acquire and may lose electricity or magnetism, but it cannot acquire and cannot lose weight.

Electric and magnetic forces not primary.

Static and kinetic energy.

Energy is either potential or actual.[1] Energy is also either static or kinetic.[2] All potential energy is static; but actual energy may become static.

Strained elasticity.

The simplest case of static actual energy is that of strained elasticity. If work is done, for instance, by bending a spring or stretching a piece of india-rubber, the work done is represented by the static actual energy due to the strained elasticity; and when the spring or india-rubber starts back to its original shape, it parts with the energy, which then assumes some other form. A spring

[1] See p. 20.

[2] Kinetic, from κινέω, to move. Professor Rankine uses the terms potential and actual energy where I speak of static and kinetic. He consequently classes as a kind of potential energy what I call static actual energy. The difference is only one of words.

that has just been suddenly released from tension, will, if it is elastic enough, vibrate rapidly for some time; the energy of motion due to its vibrations has been produced by transforming the static energy that was due to the straining of its elasticity: and the vibrations continue until their motion is carried away by being transferred to the air and to the substances surrounding the spring.

Vibrating strings.

So, when the string of a musical instrument is drawn to one side, the energy that has done work in drawing it is transformed into the energy due to its tension: and as it vibrates, the energy vibrates back and forward between the static and kinetic forms: being static at the extremities of the vibration, where the string has no velocity, and kinetic in the middle, where its velocity is at the greatest. This is an exactly parallel case to that of the oscillatory transformation of energy between the potential and actual forms in the motion of the pendulum:[1] for the principle of the transformation is not affected by the fact that, in the case of the pendulum, the energy at the extremity of the stroke assumes the static potential form, and in the case of the vibrating string it assumes the static actual form.

Energy of motion, heat, and radiance are all kinetic forms of energy: and so is current, or voltaic, electricity. Static electricity is a form of static actual energy: and in a note to this chapter I shall give reasons for believing that, as heat consists in molecular motion, so magnetism, and probably electricity, consist in the straining of peculiar molecular tensions.

But in the chapters on chemical energies and on vital energy I shall have to describe forms of static actual energy of which we cannot give any such explanation, or indeed any explanation whatever.

Transformations of static energy.

It ought to be mentioned here, that it is possible for one form of static energy to be transformed into another without passing through any intermediate kinetic state. For instance, the water that descends in the buckets of an

[1] See p. 20.

old-fashioned water-wheel (not a turbine) moves with so small a velocity, that its energy of motion may be regarded as nothing in comparison with the amount of energy of motion that it would attain if it were permitted to fall unobstructed. If, then, the water-wheel is employed in raising weights, the potential energy given out by the descending water is transformed into the potential energy of the raised weights, without any intermediate formation of energy of motion. Of course the same kind of transformation is possible between the static energy of a raised weight and the static energy of a compressed spring.

NOTE.

ELECTRIC AND MAGNETIC ENERGY.

In this note I intend to give my reasons for believing that electricity and magnetism consist in the straining of molecular elasticities.

Electro-dynamic induction.

Let two conducting wires, A and B, be placed alongside of each other: or, what is better in many experiments, twisted together into a hollow spiral, but kept from metallic contact by some non-conducting substance. Let an electric current be allowed to flow along A for an appreciable time, and then cut off: on the current beginning to flow along A, a momentary current flows along B in the *opposite* direction to that along A; and on the current ceasing to flow along A, another momentary current flows along B in the *same* direction as that along A.[1]

Experiment I.

Experiment II.

Explanation.

The most probable interpretation of these facts is, that at the moment when the current begins to flow along A, the molecules of B are thrown into a state of elastic tension: the act of the molecules of B, in assuming the state of tension, constitutes the first current along B; and the second current (which, as stated above, is in the opposite direction to the first) is constituted by the act of the molecules of B, on the cessation of the current along A, falling back into their normal state.

[1] De la Rive on Electricity, English translation, vol. i. p. 355.

If this interpretation is true, (and it appears to me the only possible one,) it follows that during the flow of the current of A, and between the flow of the two momentary currents of B, a definite quantity of energy has become static in B, due to the tension of its molecules. And, as ought to be the case on this hypothesis, the longer are the wires, the greater will be the force of the current of B;[1] for, supposing the force of the tension to be given, the quantity of energy due to the tension will obviously be in proportion to the length of the wire. In other words, the greater is the length of wire that is thrown into a state of tension, the greater will be the quantity of energy due to its tension.

But as no process can either create or destroy energy, the energy that has become static in B must have come from somewhere; and its only assignable source is the current of A. This is corroborated by the following facts:—

The current of A is the *inducing* current, and those of B the *induced* currents. It is possible to leave out B, and to obtain the induced currents in A: in other words, it is possible to obtain the induced currents in the same wire with the inducing current. Let A be sufficiently long, and let B be left out; let the current along A be stopped by breaking contact suddenly; in the act of breaking contact there will be a momentary increase of the force of the current, producing a spark. This increase of the current is evidently the same as the current that would have been induced in B, had B been there, *in the same direction* as that of A. The two currents, the inducing and the induced, flow for the moment along the same wire and in the same direction, and the spark is due to the *sum* of their effects. Experiment III.

But the current induced in B, at the commencement of that of A, is *opposite in direction* to that of A: so that if the inducing and the induced currents can be caused to exist at once in the same wire, the resultant current will be due to their *difference*. This may be experimentally shown. If B is left out, and A long enough, the current will be sensibly diminished in force at the moment of its commencing to flow along A.[2] Experiment IV.

[1] De la Rive on Electricity, English translation, vol. i. p. 358. These facts were discovered by Faraday, who at first gave an explanation of them with which mine is substantially identical. He called the state of tension into which wire B is thrown the *electro-tonic state*. He afterwards, however, changed his opinion on grounds which I do not understand.

[2] Ibid. pp. 359, 360.

Explanation.

According to my explanation, the momentary slackening of the current at its commencement is caused by a portion of its energy being taken up, and becoming static, in throwing the wire into a state of molecular tension; and the momentary increase of the force of the current at the moment when it is cut off is caused by the energy that was static in the wire returning to the state of kinetic, or current, electricity.

Electro-static nduction,

I have now stated the most important facts of electro-dynamic induction, and, as I believe, given a satisfactory interpretation of them. And I believe, though the evidence is not nearly so strong, that electro-static induction, as in a Leyden jar, will be explained in some similar way; namely, that the electric charge consists in some kind of molecular tension.

and continuous currents, probably both due to molecular tension.

The explanation I have given above applies only to those momentary currents which are produced by induction; it does not apply to continuous currents. But I believe that the hypothesis of molecular tension will be found to explain the facts of continuous currents also. The molecules of a conductor along which a current is flowing are, I think, shown to be in a state of molecular tension (of a different kind, however, from that of wire B) by the fact that *all the successive portions of the same current repel each other:* as is easily proved by suitable experimental arrangements.[1]

Electro-magnetic induction.

With respect to the theory of electro-magnetic induction, however, there is no difficulty whatever: it admits of an explanation exactly parallel to that which I have given of electro-dynamic induction. In other words, the induction of momentary magnetism in a soft iron bar is an exactly parallel fact to the induction of a momentary current in a conducting wire.

Experiment V.

Let an electric current be flowing along a wire coiled into a hollow spiral, and let a soft iron bar be put into the spiral; the iron will be instantaneously magnetised, and the current will for

Experiment VI.

the moment become *less* forcible. On removing the bar it at once loses its magnetism, while the current, for the moment, becomes *more* forcible.

Explanation.

These facts admit of exactly the same interpretation as those of induced currents. When the iron is put into the spiral, and the current for a moment loses force, the slackening of the current is caused by a portion of its energy being taken up and becoming static in the iron, which it throws into a peculiar state

[1] De la Rive on Electricity, English translation, vol. i. p. 231.

of molecular tension, constituting the magnetised state. And when the iron is taken out of the spiral, the energy that was static in the iron becomes kinetic in the wire, and increases for the moment the force of the current.

Thus the facts of electro-dynamic and of electro-magnetic induction are not only themselves parallel, but admit of a parallel interpretation ; and this tends to confirm it for both.

Besides this, there is other and more direct proof that soft iron, when temporarily magnetised by the passage of an electric current near it, is in a state of tension.

Instead of moving the iron bar into and out of the spiral while the electric current is flowing, let the iron remain in the spiral while the current is turned *on* and *off;* the act of turning the current *on* will magnetise the iron, and the act of turning it *off* will demagnetise the iron.

Experiments VII. and VIII.

It has been ascertained by Professor Joule, that at the moment of turning the current on so as to magnetise the iron bar, the bar will be elongated by about a 720,000th of its length ; which increase of length it will lose in the moment of turning the current off so as to demagnetise it.[1] This appears to be conclusive evidence that the magnetised iron is in a state of molecular tension.

Experiment IX. Elongation of iron bar during magnetisation.

This is still further confirmed by the very remarkable fact, that when the iron bar and the wire spiral are placed as in the last experiment, and the current alternately turned on and off at the rate of several times in a second (which is easily done by means of a mechanical arrangement), sounds are heard proceeding from the iron.[2] By turning the current alternately on and off, the iron is alternately thrown into and out of a state of tension.

Experiment X.

If a *magnet* is put into a wire spiral like that used in the former experiments, while there is *no current* flowing along the wire, the approximation of the magnet will induce a momentary current in the wire ; and if the magnet is taken out again, another momentary current will be induced in the wire, but in the opposite direction. It is on this principle, although the mechanical arrangements are different, that the magneto-electric apparatus is constructed for supplying the electric light.

Sounds produced by magnetisation.

The magneto-electric machine

Whence comes the energy of the induced currents in these

[1] De la Rive on Electricity, English translation, vol. i. p. 306.
[2] Ibid. p. 303.

experiments? It cannot be from the static energy of the magnet, for the magnet loses none of its magnetism, and consequently cannot have parted with any of the static energy to which its magnetic state is due. The magnets in Mr. Holmes's electric lighthouse apparatus are stated by him rather to gain than to lose force with use. But if the kinetic energy of the electric current had to be obtained by the transformation of the static energy of the magnets, the whole stock would no doubt be expended in a few seconds at the most. The energy of the current is obtained by transforming the mechanical energy which is employed in moving the magnets. The transformation takes place *under the influence* of the magnets, and would not take place without them, but it does not take place *at their expense.*

transforms mechanical into electric energy.

CHAPTER IV.

PRIMARY FORCES.

WE have seen[1] that all energy has its origin in force: for instance, the force of gravity produces the energy of motion of a falling body. And as all forms of energy are capable of mutual transformation, it follows that any force may produce any form of energy. If gravity causes a body to fall, and in its descent it produces electricity or heat by friction, there is electricity or heat produced by gravity. But the converse is obviously not true; gravity may produce motion, but motion cannot produce gravity: chemical affinity may produce electricity or heat, but neither electricity nor heat can produce chemical affinity. The ultimate origin of all energy is in primary forces; and primary forces are defined as forces which do not originate in any other forces, but are to be directly referred to the laws of nature, and have their origin directly in creative power.

Force originates energy, but energy cannot originate primary forces.

Primary forces defined.

Thus the attractive and repulsive forces of a magnet or of an electrised body are not primary forces, because they are not to be referred to the ultimate properties of the bodies. The electrical attractions and repulsions of a body that has been electrised by a common electrical machine are due to the charge of electric energy which the body has taken up; and this electric energy has been obtained by the transformation of the mechanical energy that worked the machine.[2] And the magnetic attractions and repulsions of an iron bar that is magnetised by the passage

Instances of forces not primary.

[1] P. 19. [2] P. 30.

of an electric current are due to the charge of magnetic energy which, as I have endeavoured to prove, is obtained by the transformation of the energy of the electric current, and taken up and, as it were, for the time incorporated with the iron.[1] None of these forces are primary forces, because the bodies have acquired them and may lose them.

Three primary forces, gravity, capillarity, and affinity.

There are three, and only three, kinds of primary force. These are: 1, Gravity; 2, Capillary attraction; and, 3, the attraction of chemical elements that seek to combine (as, for instance, oxygen and hydrogen, or oxygen and carbon), or, to use the common but very infelicitous term, chemical affinity. For the sake of brevity let us call these gravity, capillarity, and affinity. Capillarity is of much less importance than the other two, but I mention it in order to make the enumeration complete.

Their properties.

Gravity acts at all distances, and is for that reason a force acting on masses—a *molar* force. Capillarity acts only at insensible distances; in other words, it acts only when bodies are in immediate contact. It is for that reason a force acting on molecules—a *molecular* force. Affinity also acts only at insensible distances; but there is this difference between capillarity and affinity, that capillarity acts on the molecules into which a body may be broken up by mere mechanical division, while affinity acts on the chemical atoms which are the constituent parts of the molecules. Affinity is consequently an *atomic* force.[2]

Gravity, acting at all distances, is, probably for that reason, always in action—all matter is always attracting all other matter. Capillarity and affinity, acting only at insensible distances, act, probably for that reason, only under favourable circumstances; capillarity is chiefly

[1] See Note to Chapter III.

[2] When I speak of molecules and atoms, I only mean the smallest integrant and constituent parts, without implying any opinion as to whether or not these are infinitely small. I speak of the molecules of a body in the same way that mathematicians speak of infinitely, or indefinitely, small arcs of a curve.

confined to the liquid state of matter; and affinity generally, if not always, requires a certain degree of elevation of temperature before it will act. Combustion, for instance, which is the most energetic of all chemical actions, in most cases will only commence at a very high temperature, and never, so far as I know, at a very low one.

Gravity is incapable of saturation; that is to say, whatever be the quantity of matter that any mass of matter is attracting, it is capable of attracting any additional quantity with exactly the same force as if it had no other to attract. In briefer language, all matter attracts all other matter. Capillarity, on the contrary, is capable of saturation: as capillarity acts between molecules only when they are in contact, the capillarity of a molecule of (for instance) water or mercury for other molecules of the same liquid is in a state of saturation so long as it is surrounded by other molecules of the same liquid; all its capillarity is employed in attracting them, and it cannot attract, or be attracted by, any more. Affinity also is capable of saturation. One volume of hydrogen, for instance, does not attract all oxygen, but only one half-volume of oxygen; and when these are combined to form water, their affinity for each other is saturated; the water has no further affinity for either hydrogen or oxygen.

Gravity is not an elective force; that is to say, it acts on all matter alike: all matter attracts all other matter with a force directly as the mass. Capillarity, on the contrary, is elective; that is to say, some, probably all, liquids have a stronger capillarity for some substances than for others. Mercury, for instance, has a strong capillarity for itself, as is shown by the way it runs into globules; but it has very little capillarity for other substances, except metals. Oil, on the contrary, has a stronger capillarity for most solids than for itself, as is shown by its rising in a wick and spreading over surfaces, in opposition to gravity. But oil and water, or water and mercury, have hardly any capillarity for one another, and refuse to mix, or even to adhere. Affinity also is elective: oxygen, for instance, has a very

strong affinity for hydrogen, carbon, and iron, but hardly any for nitrogen.

The potential energy due to gravity becomes actual by the falling of bodies, in which act it is transformed into energy of motion. When the potential energy due to capillarity becomes actual, it also is transformed into energy of motion: this takes place when two drops of mercury or of water rush together. But affinity differs fundamentally from these two, in that its potential energy, when it becomes actual, is not transformed into energy of motion, but into heat or electricity. Combustion is not only the most familiar but the best instance of the transformation of chemical potential energy: the heat of combustion is the transformed energy due to the affinity of the oxygen and carbon that combine in the act of combustion. But in many cases of combination it is possible, by means of the arrangement of the voltaic battery, to obtain it in the form of electricity instead of heat.

When the potential energy of gravity or capillarity becomes actual, the change in the form of the energy does not determine any change in the character of the bodies. Water, for instance, does not change its character in falling, nor do drops of water change their character as water in rushing together by reason of their capillarity. But when the potential energy of affinity becomes actual, the transformation of the energy is always accompanied by a change in the character of the substances; they combine, and the compound has properties unlike those of either of the constituents.

Summary of their properties.

To sum up: Gravity acts at all distances and at every moment; it is incapable of saturation, and is not elective. Capillarity and affinity, on the contrary, act only at insensible distances, and under favourable circumstances; they are capable of saturation, and are elective. Gravity and capillarity, when their potential energy becomes actual, produce it as motion, and the character of the substances remains unchanged. Affinity, on the contrary, produces the energy in the form of either heat or electricity, and

the substances combine, forming a compound with new properties.

It is a very important generalization, that *all primary forces are attractive;* there is no such thing in nature as a primary repulsive force. For this, as for every other ultimate physical law, no *cause* can be assigned except the Divine will. But its *purpose* is obvious. The universe is held together by attractive forces; and if, as I believe, the nebular, or, as I prefer to call it, the condensation theory of world-formation is true, the universe has been formed by the action of attractive forces. Repulsive forces, on the contrary, it is obvious, could neither form a world nor hold it together.

All primary forces are attractive.

Purpose of this.

It needs no proof that gravitation and capillarity are attractive forces. In the case of affinity this is not quite so evident. But we know that the action of chemical forces tends to union, and not to separation; and we know also that it tends to condensation. The proof of this latter assertion is, that (among gases, in which alone it is possible to study chemical forces purely and simply) the volume of a compound is *often less* than the joint volume of its constituents when uncombined, and *never greater.*[1]

From the truth that all primary forces are attractive, it follows that potential energy is never *in a body,* but always *between two bodies;* being due to their mutual attraction, for attraction must be between at least two things. The energy due to the mutual attraction of two bodies is not a function of either body separately, but a joint function of the two. The potential energy due to a weight that is ready to fall is a function neither of the weight nor of the earth that attracts it separately, but of both jointly. The potential energy due to the capillarity of two rain-drops that are ready to run together is a function of neither

Potential energy is a joint function of two mutually attracting bodies.

[1] The immediate effect of the combination of oxygen and hydrogen is an increase of their volume so great as to be capable of causing an explosion. But this is due to the production of heat; and if the water, which is the result of their combination, is in the form of vapour, or steam, at the same temperature and pressure as the oxygen and hydrogen before combination, it occupies only two-thirds of their joint volume.

separately, but of both jointly. And the potential energy due to oxygen and carbon that are ready to burn together, is a function of neither separately, but of both jointly.

No distinction between combustibles and supporters of combustion.

It follows from this last remark, that the common distinction between combustible substances and those which support combustion has no foundation in the nature of things. We can burn a jet of oxygen in an atmosphere of hydrogen, just as we can burn a jet of hydrogen in an atmosphere of oxygen. The definition of combustion is *the rapid combination of two substances* (of which oxygen is generally, but not always, one) *with great production of heat;* and the one burns as truly as the other.

Forces belong to the original constitution of matter.

Another result of the highest importance is, that matter is endowed with active forces, as a part of its original constitution.

The laws of the conservation of momentum, the conservation of rotation, and the conservation of energy, have nothing to do with the nature of the force, or with the source of the energy; they are equally true, whether the forces that we have to consider in any case are primary forces, like gravity, or acquired ones, like magnetism: and they are equally true, whether the energy is the result of the mutual actions of the bodies under consideration, as for instance in a steam-engine at work; or whether it is the result of some force that has acted from without, as when we spin a gyroscope.

Theory of Descartes

It was, I believe, the opinion of Descartes, and regarded as probable by Locke, that matter had no dynamical properties except the merely passive capacity of being acted on by force, and of transmitting the action on to other matter: that it was by its original constitution without active forces, and was set in motion by the same supernatural Power that created it. I do not see how this theory was ever reconcilable with the most obvious of all dynamical facts, that of weight; and all that modern research has taught of dynamics and

disproved.

chemistry proves the theory to be entirely wrong; it shows that matter possesses, as part of its original constitution, not only passive properties, but the active forces of gravity, capillarity, and affinity. In other words, matter possesses,

as part of its original constitution, not only the capacity of being acted on by force, but the power to exert force on other matter.

Matter may have none but dynamical properties.

But the progress of science has not only made it certain that matter has active dynamical properties as well as passive ones; it has made it doubtful whether matter has any other than dynamical properties.

It used to be said that matter was extended and impenetrable. But what we have learned of general and chemical dynamics makes it possible, and perhaps probable, that matter, in its ultimate constitution, is not extended; for it is as likely a supposition as any other, that the ultimate molecules of matter are mere points, having position and mobility, but no magnitude or extension; which points, however, are the centres of various kinds of attractive forces by which they act on other molecules, and are also endowed with the passive capacity of being acted on by similar forces proceeding from those others. If this is true, it follows also that matter, in its ultimate constitution, is not impenetrable. "The impenetrability of matter" means that two portions of matter cannot occupy the same space. But the facts of chemical combination appear to contradict this; for in many cases the compound occupies less space than the sum of the spaces occupied by its constituents before combination (in the case of watery vapour, for instance, only two-thirds); and the most obvious interpretation of such facts is, that the ultimate atoms of the two constituents coalesce, and occupy the same point in space. On this supposition, the atom of water, for instance, consists of an atom of hydrogen and one of oxygen, which have coalesced and come to occupy the same point.[1]

May not be extended,

and not impenetrable.

I do not say that this theory of the nature of matter is true: I say it is possible; and that we consequently

[1] On this subject of the constitution of matter, see Faraday's Essays on Physics, in which he has revived Boscovich's theory of matter, according to which matter consists of mere mathematical points, which are centres of various kinds of force; and applied it to chemical facts that were unknown to Boscovich.

cannot safely assert that any properties necessarily belong to matter (other than position in space and mobility) except active and passive dynamical ones; that is to say, except the power of acting by its forces on other matter, and of being acted on in return. We thus know matter only as a function of force, just as we know force only as a function of matter.

CHAPTER V.

CHEMICAL ENERGIES.

WE have seen[1] that the quantity of energy given out in the fall of a weight is proportionate to the weight multiplied into the height through which it falls; and that this energy is exactly sufficient to raise it again to the height from which it has fallen. This last is a result of the law of the conservation of energy.

Energy given out in combination, a constant quantity,

It is equally true that the quantity of energy that is given out, in the form of heat or electricity, by the combination of any two elements, is proportionate to the quantity of the compound formed, being constant for the formation of equal quantities of the same compound. One pound of hydrogen, for instance, in uniting with oxygen to form water, gives out as much heat as would raise the temperature of 34,462 pounds of water by one degree centigrade.[2] And it is a result of the law of the conservation of energy, and is amply proved by experiment, that the energy given out in the formation of a given quantity of water or any other compound is exactly sufficient, if it were applied in the form of a current of electricity, to decompose the compound back into its constituent elements.

and sufficient to decompose the compound.

Of course it is not possible actually to decompose a pound of water by the energy given out in the formation of another pound of water. In chemical experiments there is always great loss of energy by what may be com-

[1] P. 19.

[2] All the numerical data referred to in this chapter are given in the Appendix to Miller's Chemistry, on the authority of Fabre and Silbermann.

pared to friction: the energy so lost, as in mechanical friction, is converted into heat and dissipated, and cannot be got back.

Gravitation and affinity.

The spontaneous combination of elements, in consequence of their mutually attractive force, may be compared to the fall of a weight by gravitation; and the separation of elements by electro-chemical decomposition, in opposition to their mutual attraction, or affinity, may be compared to the forcible lifting up of a weight. When the weight falls, or when the elements combine, potential energy becomes actual; when the weight is lifted, or when the compound is decomposed, actual energy becomes potential.

Energy once become actual has been parted with.

It is most important clearly to understand, that in all cases of spontaneous combination the energy *has been parted with.* In ordinary dynamics every one understands this: every one is perfectly well aware that when the water of a mill-stream has fallen so low that it can fall no lower, it is impossible to get any more motive power out of it, and motive power means *useful* energy. But in chemistry it is not universally understood. Intelligent men still speak of the power, or energy, *locked up* in every drop of water, when they ought to speak of the energy that *was given out* millions of years ago, when the water was formed by the combination of oxygen and hydrogen; and to speak of it as energy, or motive power, is the same kind of error that it would be to speak of the pressure of the ocean on its bed as if any motive power were due to it. Water is burnt hydrogen, and hydrogen, or any other combustible, will not burn again after being burned. A story is told, and is not at all too good to be true, of an iron-master who had learned enough of chemistry to know that water is composed of a combustible substance and a supporter of combustion: he inferred that it must have the properties of both its constituents, and tried the experiment of blowing a furnace with steam instead of air, but of course he only blew it out.

Misconceptions.

Anecdote of an iron-master.

When two moving bodies come into collision and bring each other to rest, we say that their opposite momenta have

destroyed, or neutralized, or cancelled each other; and this statement is true, but it is not the whole account of what takes place. It does not tell what has become of the energy due to the motions that have disappeared. This energy, however, has been transformed into heat. Just in the same way, when we say that water is formed by the combination of oxygen and hydrogen, this statement is true, but it is not the whole account of what takes place. In order to give a full account of it, we must say that water is formed by the combination of oxygen and hydrogen, *and the liberation of a definite quantity of energy in the form of heat.* Energy is as real as matter, and the liberation of the energy is as essential a part of the process as the combination of the oxygen and hydrogen.

Though the facts of chemical dynamics which I have stated are universally recognised as true, I am not sure that their importance is yet in general sufficiently felt, even by scientific men. I proceed to submit the plan of an addition to the chemical notation in general use, which would, I believe, give them no more than their due prominence.

In the preceding part of this chapter, I have endeavoured to make the subject intelligible to any person of ordinary intelligence, who is willing to give it the needful attention. In what follows, on the contrary, it is necessary for me to presume on the reader's acquaintance with chemical notation.

When two substances spontaneously unite and form a compound, as for instance when a volume of hydrogen unites with half a volume of oxygen to form a volume of watery vapour, we write the symbol of the compound in such a form as this: (I use the new notation, in which the equivalents of all substances, when in the gaseous or vapoury state, are supposed to have equal volumes:)—

Chemical notation expressive of combinations.

$$H\ O^{\frac{1}{2}};$$

and this is a true statement, but it does not state the whole of what takes place; for it tells nothing about the energy which, in the act of combination, is transformed

from the potential into the actual state, and given out as heat or electricity. Yet energy has as real an existence, and is as definitely measurable by quantity, as oxygen or hydrogen; and consequently, in order to give a full account of what takes place so far as a formula can give it, the equation ought to state not only what elements combine, and in what proportions, but also how much energy is given out in the act of their combining.

Proposed addition to it.

I propose to do this as follows. The quantity of heat that will raise the temperature of a pound (or any other unit-weight) of water by 1° centigrade is called by writers on the subject a *heat-unit*. As already stated, the combination of a pound of hydrogen with oxygen, so as to form water, gives out enough of heat to raise the temperature of 34,462 pounds of water by 1° centigrade. In other words, 34,462 heat-units are given out in the formation of water, and 34,462 is the *thermal equivalent* of water. I propose to write θ as the symbol of a heat-unit. The symbolical expression for water will then be:—

Heat-units.

Thermal equivalents.

$$H\ O^{\frac{1}{2}} - 34{,}462\ \theta;$$

indicating by the use of the negative sign that the heat, or its equivalent in electricity, *has been parted with:* and when the sign of the thermal equivalent is negative, I propose to call the compound *thermo-negative.* All compounds formed by the spontaneous combustion of their elements are thermo-negative: that is to say, heat has been given out in their formation. Products of perfect combustion, such as water and carbonic acid, are necessarily thermo-negative.

Thermo-negative and

But with some substances the sign of the thermal equivalent is positive: and I propose to call them *thermo-positive* substances. Nitrous oxide is one of these. Its symbol, written as I propose, is[1]

thermo-positive compounds.

$$N\ O + 9{,}232\ \theta;$$

[1] "In the experiments of Dulong it appeared that when oxide of carbon, or hydrogen, was burned in protoxide of nitrogen [nitrous oxide], a larger amount of heat was evolved than when the same weights of these gases were burned in oxygen. Following up this observation, Fabre and Silbermann were led to the remarkable conclusion that protoxide of nitrogen,

that is to say, instead of giving out heat in the act of formation, it takes up 9,232 heat-units, which reappear as heat when it is decomposed.

Thermo-positive compounds are never products of combustion, but are always formed by indirect methods. As a general rule, they appear to be less stable and more chemically active than thermo-negative compounds. Many compounds of nitrogen are chemically very active; nitrous oxide, already mentioned, is by no means the most remarkable of these. Gun-cotton and the fulminating salts are compounds of nitrogen, and are in all probability highly thermo-positive. It has often excited surprise that the compounds of nitrogen should be so active when nitrogen is itself so inert, but most probably the inertness of uncombined nitrogen is in some way connected with the power of nitrogen to take up large charges of energy in its compounds.

Peroxide of hydrogen.

Peroxide of hydrogen is from this point of view a very remarkable substance. It is altogether misleading to write its symbol

$$H\ O.$$

It is really a thermo-positive and very unstable oxide of water:[1] it is easily decomposed into water and oxygen, and in this decomposition heat is produced. Writing water as before,

$$H\ O^{\frac{1}{2}} - 34{,}462\ \theta,$$

peroxide of hydrogen should be written

$$(H\ O^{\frac{1}{2}} - 34{,}462\ \theta)\ O^{\frac{1}{2}} + 10{,}904\ \theta.^{2}$$

in the act of decomposition, evolves a considerable amount of heat: and they estimate that not less than 1,154 units of heat are evolved in the separation into its elements of a quantity of nitrous oxide which contains one gramme of oxygen." (Miller's Chemistry, Appendix.) Multiplying 1,154 by 8 for the atomic weight of oxygen, we have 9,232, the thermal equivalent in the text.

[1] It is not necessary for my present purpose to enter on the question as to its being a compound of antozone with water.

[2] Fabre and Silbermann "estimate the heat evolved during the liberation of one gramme of oxygen from peroxide of hydrogen at 1,363 heat-units." (Miller's Chemistry, Appendix.) Multiplying by 8 as before, we have 10,904 as the thermal equivalent.

I do not propose this notation as adapted for general use, but I believe that it would be a concise and lucid way of stating important facts: and it could not cause any confusion, because the present notation would not be in any degree changed, but only added to.[1]

But what is there in a thermo-positive compound to represent the energy that appears as heat on its decomposition? I cannot suggest any answer whatever to this question. It is a form of static actual energy, but, unlike electricity and magnetism, it does not appear to be any kind of strained elasticity.

Nor can we tell what there is, in or between[2] two elements previous to their combination, to represent the energy that they give out, as heat or electricity, on their combination. The emission of heat is not due, as Lavoisier supposed, to condensation. Such a cause is probably inadequate in nearly all cases, and in the case of the combination of hydrogen with chlorine it fails altogether; for after they have combined and formed hydrochloric acid gas, they continue to occupy the same space as before. The tendencies of elements to combine, and to give out energy on combining, are in all probability ultimate properties, no more to be explained or accounted for than gravitation. But this very important question remains for solution: Can we assign dynamic equivalents to the elements? We know the thermal equivalents of many products of spontaneous combination, as water, hydrochloric acid, and carbonic acid. Can we assign dynamic equivalents to their elements, so that the thermal equivalent of any compound (that is to say, the quantity of energy which from being potential in the elements becomes actual in the act of combination) shall be the sum, or the product, or some other joint function, of those equivalents of their elements?—just as the potential energy due to

Dynamic equivalents of the elements.

[1] It might also prevent mistakes from being made by classing substances of unlike thermo-chemical properties in the same or homologous series. But I do not know enough of the higher chemistry to be certain whether there is any danger of this.

[2] See p. 43.

the mutual gravitation of two bodies is proportionate, supposing the distance given, to the product of their masses.

What greatly increases the difficulty of any such inquiry is, that in the case of many thermo-negative substances, the potential energy of their elements is not all parted with in the act of combination; some of it remains in the compounds, and is converted into heat when they again enter into combination. To take an instance almost at random, hydrochloric acid and potash are both thermo-negative; and yet when an equivalent of the one combines with an equivalent of the other, they give out no less than 15,656 heat-units. Neutral salts are perhaps the only perfectly thermo-negative substances: and, containing no potential energy, they do not seek to combine with others. They may be compared to a body which has no potential energy due to its position, and is in stable equilibrium because it can fall no lower.

In order to discover these dynamic equivalents (if they exist, which appears highly probable), it will of course be necessary in the case of each element to observe the quantities of heat it gives out in combining with various other elements, and the quantities its compounds again give out in their combinations. The problem is no doubt a difficult one, but it ought not to be very much more difficult to us than was the determination of the combining equivalents to Dalton.

Some simple substances appear to be capable of entering into a thermo-positive state. Phosphorus is the most remarkable instance of this yet known: it is capable of assuming the allotropic state called red or amorphous phosphorus, in which it has taken up a considerable quantity of heat. If red phosphorus is heated up to a certain point, it suddenly passes back into the ordinary colourless state, and the heat which it had taken up is given out in such quantity as to vaporize a part of the phosphorus.[1] The number of heat-units has not been determined, so far

Red or amorphous phosphorus.

[1] Miller's Chemistry, vol. ii. p. 201.

as I am aware. If we call it x, then, the symbol of common phosphorus being

$$P,$$

that of red phosphorus, in the notation that I propose, will be

$$P + x\,\theta.$$

NOTE.

Inaccurate language respecting affinity as a force.

VAGUE and inaccurate language is still general concerning the relation of chemical affinity to the various forms of energy. Thus Mr. Grove says :—

"Light, heat, electricity, magnetism, motion, and chemical affinity are all convertible material affections."[1] And again, "Lastly, electricity produces *chemical affinity.*"

Now, it is quite true to say that light, heat, electricity, magnetism, and motion are all convertible, being all forms of energy, and capable of mutual transformation. But chemical affinities are not capable of transformation into anything else; so far as our knowledge extends, they appear to be primary forces;—primary underived properties of matter, and unchangeable by any action whatever. Oxygen and hydrogen, for instance, have an affinity for each other which nothing can change, or transform into anything else. While they are uncombined, this force of affinity *makes them seek to combine;* after they are combined, it *resists decomposition.*

I do not suspect Mr. Grove of any inaccuracy as to fact, or any confusion of scientific thought. I believe the expressions I object to are mere inaccuracies of language, occasioned by the proper technical language of the subject being not yet fixed. When Mr. Grove says that electricity produces chemical affinity, I presume he means that, in the electric decomposition of water or any similar substance, the electric energy is transformed into the chemical potential energy due to the mutual affinity of the separated elements.

As gravity produces motion, but motion cannot produce gravity, so affinity produces heat or electricity, but heat or electricity cannot produce affinity.

[1] Correlation of Physical Forces, ed. 1862, p. xii.

CHAPTER VI.

THE MOTIVE POWERS OF THE UNIVERSE.

WE have seen that matter and energy are incapable of being either produced or destroyed, and capable only of being transformed; and it is an obvious inference from this that the universe has existed from an eternal past, and will continue to exist through an eternal future. It appears at first sight a probable theory that all changes that go on in the universe are like the motions of the planets in their orbits, which, after a shorter or longer period, end at the point where they began. It appears as if we had good ground for the belief, which was that of many ancient philosophers, that cosmic changes (to use a mathematical metaphor) move in closed curves; and that at the end of a finite though very long cycle, or *annus maximus,* all things will return to their state at its beginning.

Theory the past and future eternity of the present order of the universe

But a profounder knowledge of the laws of energy shows that such an inference is untrue. It shows that the universe has not existed from an eternal past. It shows that cosmic changes do not come back to the point where they began: that they do not move in closed curves, but in open spirals; though in the historical periods these spirals are not distinguishable from closed curves.

untrue.

The reason of this is the destruction of motive power which is always going on. Energy is indestructible, but motive power is constantly diminishing in quantity. Motive power is defined, for the purposes of the mechanic, as *useful energy* — energy that he can transform as he

Reason of this.

Definition of motive power.

desires. In a broader scientific sense, motive power is to be defined as *energy that is capable of transformation* into some different form of energy;[1] and in this sense, energy is not always motive power. Potential energy, as we have seen, is capable of transformation into actual, and the actual energies of motion and electricity are capable of transformation into heat. But the converse is not necessarily true. All other forms of energy are capable of transformation into heat, but heat is not always capable of transformation back again into other forms of energy. The heat in the furnace of a steam-engine is capable of being used as motive power; not because the furnace is *hot*, but because it is *hotter* than the surrounding air. But if the surrounding air were as hot as the furnace, and no supply of cold air or cold water could be brought in, no part of the heat could be converted into motive power.

Heat is not always motive power.

Heat is capable of becoming motive power only in the act of attaining to equilibrium: and consequently, *no motive power is due to heat in perfect equilibrium.*

Illustration from a steam-engine.

Suppose the case of two bodies of unequal temperatures, which for the sake of a practical illustration let us call the boiler and the condenser of a steam-engine; and suppose that the heat of the boiler is flowing towards the condenser, so as to establish equilibrium. If the condenser is perfectly cold, all the heat of the boiler is theoretically capable of being used as motive power; but if the condenser, though colder than the boiler, is not perfectly cold, only a portion of the heat of the boiler can be so used. This last condition is the one that always occurs. Perfect cold is never found, nor can it be obtained by any known process: perfect cold—the absolute zero of temperature, or the total absence of heat—would be 492° Fahrenheit below the temperature of freezing water. Consequently, under the most favourable circumstances

[1] To be rigidly accurate, we should say that motive power is energy that is capable of transformation into some different form of energy, *other than radiance.* Heat is motive power in being transformed into motion, but it would be absurd to say that heat is motive power in being transformed into radiance—that is to say, in being radiated away.

that can occur, in any natural or artificial combination, only a portion of any mass of heat can become motive power.

The whole of what I may call a *mass* of energy of motion is capable of being transformed into heat. For instance, when a railway train is stopped by the action of its break, the energy of its motion is all transformed into heat. This transformation is constantly and everywhere going on throughout the world; it almost always takes place when motion ceases. But, as we have seen in speaking of the steam-engine, the whole of what I may in like manner call a *mass* of heat is *not* capable of being transformed into energy of motion,[1] or into any form of potential energy.

Transformation of energy of motion into heat, the prevailing tendency.

Thus any mass of energy of motion *can* be *all* transformed into heat, but the heat *cannot* be *all* transformed back into energy of motion. It follows from this, that though both of these transformations are constantly going on, more energy of motion is transformed into heat than can be transformed back again; and, as these are by far the most abundant forms of actual energy, the energy of motion in the universe is being gradually transformed into heat. Of course we do not assert that all the energy of motion in the universe will ever be thus transformed. We do not assert it of the planetary motions. But it is certain that such is the tendency of all change.

Consequent destruction of motive power.

We thus see that motive power is constantly transforming itself into heat, and that heat is constantly attaining equilibrium: and heat in equilibrium, as we have seen, is not motive power. It follows from this that a constant destruction of motive power is going on throughout the universe; there is less motive power in existence at present than there was in the past, and there will

[1] The relation between heat and electricity is in this respect the same as that between heat and energy of motion. Heat can be transformed into electricity only in the act of attaining equilibrium: when heat is in equilibrium, it cannot be transformed into electricity, or into any other form of energy whatever. The whole of a mass of electricity can be transformed into heat, but the whole of a mass of heat cannot be transformed into electricity.

be less motive power in the future than there is in the present.

Dissipation of energy.

This is called the law of the *dissipation of energy*. For my present purpose I prefer to call it the law of the *destruction of motive power*.

It follows from this law, that, as I have stated at the commencement of this chapter, the changes of the universe do not come back to the point from which they began: the diminishing quantity of motive power makes a difference.

Consequences of the greatest importance to science follow from the two closely united truths, that energy is invariable in quantity, and that motive power is constantly diminishing.

Earth's internal heat is constantly being lost.

Among other inferences may be mentioned that as the earth is constantly though slowly parting with internal heat by volcanic eruptions, by hot springs, and by slow conduction outward through the strata; and as all volcanic action depends on heat—not eruptive action only, but all subterranean action whatever; it follows, as I believe, that the intensity of volcanic action has been constantly diminishing ever since the formation of the earth; and

Geological consequence.

consequently, that geological changes went on in past times with greater rapidity than they do at present.[1] I admit that geological evidence of this is scarcely to be hoped for, but I regard it as an *à priori* certainty.

Sun's heat.

What is true of the heat of the earth is also true of the heat of the sun. The sun is radiating away his heat, and it must be exhausted if fresh supplies are not brought in from without. But our increasing knowledge of the physics of the universe has suggested a mode in which such supplies may probably be brought in.[2] It has been proved beyond

Meteoric theory.

all reasonable doubt, that the meteors which flash across our sky are small planets that fall from without into our

[1] I do not believe there is any evidence in favour of the chemical theory of volcanic action. But should that theory prove true, the conclusion in the text will not be affected; for energy from a chemical source obeys exactly the same laws as energy from a mechanical source.

[2] See Professor (now Sir William) Thomson's article on the subject in the Philosophical Transactions for 1854.

atmosphere; and the energy of motion that they had as planets is transformed into heat by friction against the air.[1] Their brilliant light is due to intense heat, and when they fall as meteoric stones, these stones are intensely hot. This is at least a possible origin of solar heat. It is calculated that a meteor, falling into the sun's atmosphere with the velocity of a planet at the surface of his atmosphere (and it cannot fall in with a less velocity than this), has energy of motion enough to be converted into a rather greater quantity of heat than would be produced by the combustion of four thousand times its weight of coal.[2]

Carrington's observation.

This hypothesis has received a very strong confirmation by Mr. Carrington and another observer simultaneously, at different places, on the 1st September, 1859, seeing two meteor-like bodies of such brightness as appeared bright against the sun, suddenly appear, rapidly move across his disc *from west to east*, and soon disappear.

There are some further reasons in favour of the meteoric theory which are little known, and are worth stating here.[3]

If there are small planets revolving round the sun and constantly falling into his atmosphere as meteors, they probably occupy, like the entire solar system, a lenticular (or very oblate spheroidal) space, having its greatest diameter nearly coincident with the sun's equator; and if so, a greater number of meteors must fall on the equatorial than on the polar regions of the sun, making the former the hottest. Such is the case. Secchi of Rome, without any theory to support, has found by the use of a thermo-electric test (the result of which is due not to the *ratio* but to the *difference* of the two sources of heat) that the sun's equator is sensibly hotter than his poles.[4]

Sun hottest at the equator, and why.

[1] And also, as has been suggested, by the compression of the air before them as they fall. It is to be remembered, however, that equal quantities of energy of motion are convertible into equal quantities of heat, in whatever way the transformation is effected.

[2] Tyndall on Heat as a Mode of Motion.

[3] What follows, on the motions of the solar spots, and on the difference of temperature at the sun's poles and equator, was first published by me in a paper read at the Newcastle meeting of the British Association in 1863, and printed in its Transactions.

[4] Nichol's Cyclopædia of Mathematical and Physical Science.

If these small planets move round the sun, it cannot be doubted that, like the larger planets, they move from west to east. Mr. Carrington's meteor, as already mentioned, moved in that direction. If, now, meteors are constantly falling into the sun's atmosphere, moving from west to east with the velocity of a planet at the sun's surface, and in greatest number nearest the equator, there is a motive power which may be expected to drive the atmosphere round the sun in the same direction, and with greatest velocity at the equator. Mr. Carrington's observations on the motion of the solar spots appear to show that such is the case. The solid globe of the sun is concealed by clouds, but Mr. Carrington has ascertained that the spots which are formed among the clouds of his atmosphere move most rapidly from west to east in the lowest latitudes, showing the relative directions of the atmospheric currents to be what the meteoric theory requires. If on the contrary the sun's atmosphere, like the earth's, were acted on by no other motive power than unequal heating at different latitudes, the relative direction of the currents would be the reverse of this, in virtue of the well-known principle of the trade-winds and "counter-trades," and this would be true at all depths in his atmosphere.

Motions of the sun's atmosphere.

The meteoric theory does not, so far as I can see, throw any light on the difficult question of the nature of the solar spots, but it suggests a reason why they should be formed where they are. They are formed only in the lower latitudes of the sun, where, as already remarked, the greatest number of meteors probably fall in, and where consequently there must be the most atmospheric disturbance.

Solar spots.

If the sun is still receiving supplies of energy for conversion into heat, and is not merely expending an original stock, the falling in of meteors is the only possible mode of such supply. The most obvious notion is that solar heat is heat of combustion. But combustion is altogether an inadequate source. We have seen that the energy of motion with which a meteor will fall to the surface of the sun is equivalent to a greater quantity of heat than that which would be produced by the combustion of four

Combustion an insufficient source.

thousand times its weight of coal; and if the quantity of heat constantly radiated by the sun were supplied by the combustion of the sun's substance, supposing the sun to be of coal, and oxygen to be supplied from without, it would be burned away in about 26,000 years[1] at the most.

Meteoric heat.

I ought perhaps to repeat, that meteoric heat is the energy of motion of the meteors, which is transformed into heat in the act of falling into the atmosphere of a sun or a planet. The intensely bright light of the meteors that flash across our sky shows how hot they must be; and in consequence of the sun's greater attractive force, the meteors fall into his atmosphere with a very much higher velocity than into ours, and, of course, produce heat in the ratio of the square of the velocity.

Infinite supply of meteors possible, but would subvert the equilibrium of the solar system.

But, however strong may be the proof of the meteoric theory of solar heat, it does not prove the supply of solar heat to be inexhaustible; for an endless supply of heat would need an infinite supply of meteors to yield it, and an infinite supply of meteors could only be drawn from infinite space. Such a supply may possibly be brought in; there is nothing in the supposition in contradiction with the laws of force; but if, in the course of ages to which all historical time is but a point, vast masses of meteoric matter fall in from regions beyond the orbits of the planets, and increase the sun's mass and consequently his attractive power, this increase of the sun's attractive power, not being balanced by any increase in the centrifugal force of the motions of the planets, will ultimately cause the planets themselves to fall into the sun.

Two alternatives: exhaustion

Consequently, one of two alternatives must be true. If the supply of meteors is limited, the sun's heat will be

[1] Were the heat radiated away by the sun supplied by the combustion of coal, it would require the combustion every year of a layer of coal about seventeen miles thick all over the sun's surface. (Tyndall on Heat, p. 419.) As the sun's radius is about 441,000 miles, this would involve the combustion of his whole substance in about 26,000 years. On this supposition, however, the sun's mass, and consequently his surface, would be constantly growing less, and would radiate less and less heat; but were the supply by any means to be kept up at the present rate, the sun would be burned out in a much shorter time.

of sun's heat, or subversion of equilibrium of the solar system.

exhausted like that of a fire that dies out for want of fuel; and this, from what evidence we have, appears the most probable alternative. Or if the supply of meteors is indefinitely great, the increase of the sun's mass by their falling in will subvert the equilibrium of the solar system. And in neither case will the future be like the past and the present.

We have seen that the law of the conservation of energy proves that the sun is radiating away his stock of heat, and cannot possibly receive any considerable fresh supply except from without. And we have seen that the law of the dissipation of energy proves that the heat thus radiated away tends to equilibrium—to equality of temperature among all the bodies in the universe; and this involves destruction of motive power.[1]

Is the universe mortal?

Are we then to infer that all things are tending to equilibrium, repose, and death?

Uncertain.

On this subject we can only make conditional assertions, as we do not and cannot know all the data.

Three cases are possible.

First case.

The universe may be finite in the midst of infinite space. In this case all the heat will be radiated away.

Second case.

The universe may be finite in finite space. Space is no doubt geometrically infinite; but the space in which our universe exists may, for anything we know to the contrary, be bounded by space which is not pervious to radiance. In this case the heat will ultimately attain to equilibrium, and cease to be motive power.

Third case.

In either of these two cases all things are tending to equilibrium of temperature, destruction of motive power, repose, and death. But a third case is possible, and has been hinted at in speaking of the possibility of an infinite supply of meteors being brought in from infinite space. The universe may be infinite, and in infinite space; the supply of motive power may be infinite, and may last through endless time. In that case, however, though the whole universe is immortal, every separate system of which it is composed must perish, as already explained, through

Each separate system is mortal.

[1] See p. 56.

the subversion of its equilibrium; but other systems may arise out of its ruins, or be warmed with the heat generated by its destruction. It is physically quite possible that meteors may continue to fall, through endless time, from the regions of infinite space into the sun and the other stars; that their mass and attractive power, being augmented by the meteoric matter, may cause their planets to fall on to their surfaces as gigantic meteors, still further increasing their mass, and renewing their stock of heat; that the stars may in like manner rush together; and so on, absolutely without end. Some one of these three cases, under some modification, must be the fact; but it is, and ever must remain, utterly useless to try to guess which is the most probable.

A past eternity impossible.

But though the universe may be destined for a future without end, it cannot have existed through a past without beginning. The sun may go on accumulating meteoric matter without end; but, as his magnitude is finite, he cannot have done so without beginning. Aggregation of masses is always going on; at the beginning, so far as we can judge, there was no aggregation, but all matter existed in a diffused state, as it appears to exist in the nebulæ now. Physical reasonings will bring us no farther back than this: "the things which are seen were not made of things which do appear."

Nebular theory.

It will be seen that I believe in the nebular theory, or, as it might be called, the condensation theory of the origin of the stars and planets. I regard that theory as no mere hypothesis. It postulates nothing as a law of nature which is not independently known to be true; and its assumption, that the laws of nature have continued unchanged since the beginning of things, is one that is implied in all the reasonings of geology. We know that the tendency of things is for masses to become more and more aggregated together, and to give out heat in the process: the laws of gravitation and of heat make this necessary, and every meteor that falls on the surface of the sun or of a planet is an instance of it. The nebular theory is, simply, that this process has gone on from the beginning;

and that every aggregate—that is to say, every star and planet—has been produced by the aggregation, or condensation, of matter that was previously in a diffused form, perhaps somewhat like that of water in a cloud.

It is to be observed that aggregation may be repeated an indefinite number of times. The original nebula may have condensed into masses no larger than meteors, and these may have coalesced into planets; the planets may ultimately swell the mass of the sun; suns may rush together; and so on, absolutely without limit, if the universe is infinite.

The smallest excess of density in one part of a nebula above the rest will produce at that place a centre of aggregation; and round it the nebulous matter will condense into a star or a planet, much in the same way that a cloud condenses into raindrops.

Transformation of energy in the process of condensation.

All the energy in the nebula was at first potential energy. When motion began in consequence of the mutual gravitation of its parts, part of this was changed into energy of motion; and when any of the moving parts struck against each other and coalesced into masses, depriving each other of part of their momentum, a part of their energy of motion was transformed into heat. Such was the origin of the internal heat of the earth (and in all probability of all planets, except those which are so small as to rank as mere meteors);[1] and such is the process by which, according to the metoric theory, solar heat is still originated.

Solar and volcanic heat have the same origin.

We thus come to the wonderful but highly probable conclusion, that solar heat and volcanic heat are of the same origin.[2]

Potential energy of the original nebula.

It has been calculated by Professor Helmholtz, that all the potential energy due to the mutual gravitation of the

[1] It is well known that the moon's surface contains marks of past volcanic activity, and this appears to be not yet extinct. (Quarterly Journal of Science for July 1867, p. 383.)

[2] The chemical theory of volcanic action is in my opinion completely disproved by the comparative absence of hydrogen flames in volcanic eruptions; for that theory requires the action of water as an oxidising agent, and this involves the liberation of hydrogen.

parts of the original nebulous mass that has condensed into the solar system, has been thus transformed into heat and radiated away, except $\frac{1}{454}$th part, which still remains.[1] Part of this is the potential energy due to the distances of the planets from the sun, and would be transformed first into energy of motion and then into heat if the planets were to fall into the sun; part is the energy of the planetary motions. In this calculation the heat of the sun and of the heated centres of the planets is left out of the account, as being almost infinitely small in comparison with the energy just mentioned as due to the planetary distances and the planetary motions.[2]

In a few words, the history of the transformations of energy in the condensation of a nebula is this: First it is potential energy due to the gravitation of the parts of the nebula towards each other; this is transformed, first into energy of motion, and then into heat; and finally the heat is transformed into radiance, and lost in space.

Rotation of a nebulous mass.

We have seen that the condensation of a nebula must necessarily result in the aggregation of masses with production of heat. It follows from the law of the conservation of rotation,[3] that, supposing the original nebula to have a slight initial velocity of rotation, the masses will rotate on their axes and revolve round their common centre of gravity, as we find those which constitute the solar system to do. But it also follows from the conservation of rotation, that if the nebula has no initial rotation, no mutual actions of its parts can cause the nebula, or the sum-total

[1] In this calculation it is assumed that the volume occupied by the nebula was infinite. This of course cannot be true, but it probably gives a nearly true result.

The total mass, or weight, of the bodies composing the solar system being approximately known, it is a matter of calculation to determine how much energy, from being potential, would become actual, in the condensation of that mass of matter from a state of infinitely wide diffusion into a globe having the density of the sun.

[2] The nebular theory was first advanced by Laplace; the best account of it that I know of is to be found in Herbert Spencer's Essays, where a wonderful amount of cumulative proof has been assembled. Of course I do not offer my slight sketch of the theory as anything like complete proof.

[3] P. 17.

of the bodies formed out of it, to rotate. But the nebulous mass out of which the solar system has condensed was in all probability only an infinitesimally small part of the original nebula, which, though perhaps not actually infinite, was probably the origin of the whole starry system known to us. The first condensation of a nebulous mass produces, not globular, but very irregular forms: we see these in those parts of the original nebula that still remain as nebulæ: the motions due to the mutual attractions of irregular forms will be very complex, and will be further complicated by the resistance of the rarer medium to the motion of the denser aggregations. Our mathematics are utterly inadequate to predict what such motions would be, but we may safely assert that most of them, if not all, will be partly rotatory; and the law of the conservation of rotation will be satisfied by the rotations in opposite directions compensating each other, so that their algebraic sum will be nothing.

Solar radiance the great motive power.

With the small exceptions of volcanic action and of the tides, all the motions on the surface of the earth have their motive power in solar radiance. It is this which sets the winds, the rain, the rivers, and the ocean currents in motion; and it is the motive power also of animal and vegetable life; for the heat and motor energy of all living beings is due to the combustion of carbon and hydrogen, and the potential energy which becomes actual in that combustion is the transformed energy of the solar radiance that has fallen on living vegetables. The same is true of the heat given out by the combustion of coal: it is the transformed radiance of the sun, which, millions of years ago, fell on the pines and ferns of the coal formations, decomposed the carbonic acid of the air, and in doing so was transformed into the potential energy due to the separation of the carbon from the oxygen; which energy reappears as heat in every coal fire.[1]

The tides.

This, of course, is not true of tidal action. The motive power of the tides is not solar heat, nor any heat

[1] Tyndall on Heat as a Mode of Motion, p. 430. This subject is to be further explained in the chapter on Vital Energy.

whatever; it is that other portion of the unexhausted energy of the original nebula which exists as planetary motion. So that whatever work is done by the tide (as for instance if it works a water-mill),[1] the energy transformed in doing that work is a part of the energy of motion due to the earth's rotation; and, by the friction of the tidal wave against the earth, the velocity of the earth's rotation is being constantly lessened, though by an immeasurably small quantity.

Energy of wind and tide; their common source.

We thus come to the wonderful but highly probable conclusion, that the motive power of a tidal current and that of a wind-driven current have both of them the same origin, in the potential energy due to the gravitation of the parts of the original nebula on each other. Part of this potential energy was transformed into the energy of motion due to the earth's rotation, and in that form became the motive power of the tidal current. Another part was transformed into the energy of motion of meteoric masses, and this into solar heat; which, after it reached the earth, was transformed back again into the motion of the winds and currents.

[1] Tyndall on Heat as a Mode of Motion, p. 425.

CHAPTER VII.

CRYSTALLIZATION.

MY purpose in this chapter is not to write an elementary treatise on Crystallography, but merely to give such an account of the principal facts of that science as may enable me to show the remarkable contrast, and the yet more remarkable points of resemblance, between crystals and organisms. I will avoid technical language as much as possible, but I fear I shall not be able to make myself intelligible, except to readers who are acquainted with the fundamental conceptions of solid geometry.

Contrasts and resemblances between crystals and organisms.

The first and most obvious point of resemblance between crystals and organisms is, that every specimen of either a crystal or an organism belongs to a species, having its specific characters; and the species of both group themselves into genera, and the genera into classes.

Species and classes.

A crystalline species is defined as *a body of definite chemical constitution, from which,* in virtue of unknown formative principles, *results a form having definite geometrical properties.* I say a form having definite geometrical properties, rather than a definite form; because the same crystalline species often contains specimens having very different forms, the "crystallographic elements" of which, however, are the same, as is hereafter to be explained.

Crystalline species defined.

There are, however, qualifications to be made in asserting the invariability of either the chemical constitution, or the crystallographic elements, among all the specimens of a crystalline species. The presence of foreign substances, or of (what is practically a foreign substance) an excess of one of the elements of a compound, often causes a sensible

Foreign substances modify forms.

degree of irregularity in the crystalline form. And if substances that crystallize in nearly but not quite similar forms are mixed together in solution, they will form mixed crystals, of a form intermediate between those proper to the two substances.

Forms intermediate between species.

The mention of mixed crystals brings us to a very important analogy between crystals and organisms. Substances that crystallize in crystals of the same form are called isomorphous substances: substances that crystallize in crystals of nearly the same form are called plesiomorphous.[1] Isomorphous and plesiomorphous substances, as just stated, crystallize together, forming mixed crystals; but when the same water contains substances in solution that crystallize in unlike forms, they do not crystallize together, but form separate crystals. The fact that mixed crystals can be formed when the crystalline forms are similar, but not when they are unlike, is a parallel to the facts, that trees may be grafted the one on the other, and that organisms can breed together, when they are of the same or of nearly allied species, but not when the species are unlike. To state these facts in terms that will apply to both crystals and organisms: if the unformed but formative material of two similar species is mixed together, it will produce an intermediate form; but this is not the case when the species are unlike. This statement postulates as true the now universally received theory of generation, of which I shall have to speak farther on.

Analogies with organisms.

Also, as crystals of unlike species in a mixed solution attract to themselves each its own material, so different species of plants in the same soil draw each from the soil the nutriment it needs; and the various tissues in an organism separate each its own material from the sap or blood.

Some substances have the property of crystallizing in

Dimorphism.

[1] Isomorphism and plesiomorphism depend on similarity of chemical constitution; and isomorphous or plesiomorphous crystals contain equal proportions of water of crystallization. Salts are similar in constitution when they contain the same number of equivalents of different bases, but not when they contain different numbers of equivalents of the same base.

two fundamentally distinct forms; that is to say, forms of which the "crystallographic elements" are different, and between which, consequently, no gradation is possible. Such substances are said to be dimorphous. Carbonate of lime is one of these: it forms crystals of the rhombohedral system which are known as calcspar, and crystals of the right prismatic system which are known as aragonite. Such crystals are to be regarded as distinct species.

As I shall have to show farther on, there are great differences of form within the limits of the same species; but these are not fundamental, and gradation between them is possible.

Crystals are bounded by plane surfaces:

A crystal, when normally formed, is always bounded by plane surfaces which meet each other at angles. In organisms, on the contrary, there is no such thing as two plane surfaces meeting at an angle.

may be described mathematically.

In every crystal, all the faces stand in simple mathematical relations to each other. In organisms, on the contrary, the forms are too complex to admit of mathematical description.

Spiral shells.

Spiral shells are an exception to this: they present regular equiangular spirals. But though this is an exception, it is one that rather confirms the rule; for though shells are vital *products*, no vital *process* goes on in their substance.

Crystals have a limit of size:

Every crystallized species, as well as every organic species, has an approximate limit of growth, and consequently a specific size, which is seldom exceeded. In crystals this is not nearly so definite as in the higher orders of organisms; but it is quite as definite as in such low organisms as lichens.

are hard:

A crystal is generally harder and more brittle than the same substance when in the non-crystalline state. In this crystals are contrasted with organisms, the substance of which is generally soft, and is always so in those parts of the organism in which growth, or any other vital process, is going on with greatest rapidity.

impermeable by water:

The substance of crystals is impermeable by water. This is true even of those crystals the substance of which is soluble in water, such as common salt: their substance

cannot be permeated by water so long as it retains the crystalline structure. In this respect, also, crystals are contrasted with organisms; for the substances that compose organisms are always in some degree permeable by water.

On this depends the fundamental difference between the mode of growth of crystals and of organisms. Crystals grow by addition of substance at the surface, and at the surface only: organisms, on the contrary, both animal and vegetable, absorb into their interior the nutritive materials that are to be added to their substance. In other words, crystals grow by superficial accretion, organisms by interstitial accretion.

grow at the surface only:

Closely connected with the last-mentioned is another difference, which also is a fundamental one. A crystal is in a state of perfect molecular immobility: its molecules cannot acquire mobility without the crystalline structure being destroyed. In an organism, on the contrary, a certain degree of molecular mobility is the first condition of life: it is constantly excreting matter, while other matter is brought in from without to supply the loss. This double process goes on with most rapidity in those organisms where the life is most energetic; that is to say, in warm-blooded animals.

are molecularly immobile. Contrast of organisms.

I have now stated the chief among what may be called the physiological resemblances and differences between crystals and organisms. Before I go on to their morphological resemblances and differences, it will be necessary to give a brief account of the morphological, or formative, principles of crystallization; of the optical properties of crystals, which stand in close connexion with their forms; and of the classes, or systems, of crystals.

For every crystalline species three lines may be found which stand in a simpler geometrical relation than any other to all the forms which are possible in the species. These lines intersect in a point within the crystal. They are called the crystallographic axes, or simply the axes. They are never all in the same plane, and they all may be at right angles to each other. The angles of their intersection are constant "crystallographic elements" for the species.

Crystallographic axes.

If any face is produced till it cuts the three axes, the portions of the axes intercepted between the point where they intersect each other and the produced faces are called the intercepts of that face. For every crystalline species, certain faces may be found, the relations of which to the axes are simpler than those of any other faces that are possible in the species. The intercepts of these faces are called the parameters of the species, or, to speak more accurately, the parameters are the numerical ratios between the intercepts of these faces. The parameters are constant for the species.

Intercepts.

Parameters:

In many cases two, or all, of the three parameters are equal. But when the parameters are not equal, they do not stand in any simple numerical ratios to each other. In topaz,[1] for instance, the parameters are approximately 1, 0·5284, and 0·47698.

their ratios.

Ratios of intercepts to parameters.

It is a universal and very remarkable law of crystallography, that the three intercepts of any face which is possible in any species, stand to each other in ratios which are either those of the parameters of the species or else simple multiples or submultiples of the parameters. When a face is parallel to an axis, as occurs for instance in the cube, the intercept of that face on that axis is infinite. In Professor Miller's crystallographic notation, instead of the ratios of the intercepts to the parameters, the reciprocals of the ratios are taken as the indices of any given face. The reciprocal of infinity is 0. In this notation, when the angles at which the axes intersect each other, and the ratios of the parameters are known, the relation of any face to the three axes may be expressed by the three indices of the face; and these are always capable of being written as whole numbers, counting 0 as a whole number. An index is seldom higher than 6. Similar and opposite faces have the same indices with opposite algebraic signs. In topaz, for instance, there may be a face with the indices 4, 2, 3; and as the values of the parameters of topaz, as stated above, are 1, 0·5284, and 0·47698, the

Miller's notation.

Topaz.

[1] Mr. Maskelyne's Lecture on the Crystal Molecule as examined by Light, at the Royal Institution, 1st April, 1859.

intercepts of such a face stand to each other in the ratios of $\frac{1}{4}$, $\frac{0.5284}{2}$ and $\frac{0.47698}{3}$.

In practice, the angles that the faces of a crystal make on each other are measured by means of Wollaston's reflecting goniometer, and the crystallographic elements are then mathematically calculated from these.

When the angles at which the axes of any species intersect each other, and the numerical values of the parameters, are known, all the crystallographic elements of the species are known: and any form is a possible one in the species (though it may not have been actually found) in which the angles of the faces on each other are such as to fulfil those conditions.

Crystallographic elements.

Consequently, two kinds of variation of form occur within the limits of the same species. The magnitude of the faces is subject to no law: and this variability, of course, gives rise to great variability of form. If the typical form of a species, for instance, is cubic, the actual form of any specimen of the species may be that of a square or rectangular prism; and from such a specimen it will be impossible to tell what the values of the parameters are. But if there are "secondary faces" cutting off the edges or angles formed by the meeting of the primary ones, the values of the parameters may be calculated from the angles made by the secondary faces on the primary ones.

Variations of form,

The kind of variability of form just described may be regarded as analogous to the irregular variability of the forms of such low organisms as lichens. But besides this irregular variability, many species are regularly variable, presenting distinct geometrical forms, of which however the crystallographic elements are the same. In crystals of the cubic system, for instance, the three axes are all at right angles, and the three parameters are all equal; these are the simplest of all possible crystallographic elements; and in this system the cube, the regular octohedron, the rhombic dodecahedron, and some others, are all found. Combined forms are also found, such as cubes with angles truncated by octahedral faces, octahedra with angles

irregular and regular.

Secondary planes.

truncated by cubic faces, and cubes with edges truncated by dodecahedral faces; and other instances of the occurrence of secondary planes on the angles or edges of the primary forms. Gradations between two of the primary forms of the same species, as for instance between the cube and the octahedron, are possible through these combined forms. But gradation between the angles of any two faces on each other is not possible: for, as already stated, the intercept of any face on any axis stands in a simple ratio to the parameter of that axis; and were there indefinite gradation, they would have to pass through complex ratios.

Transitional forms.

Analogy with organisms.

The existence of different forms within the limits of the same crystalline species may perhaps be remotely compared to the existence of those different forms within the limits of the same organic species which are related to each other as male and female, as larva and perfect form, and in other ways of which I cannot now speak particularly.

Law of symmetry.

In normally formed crystals, every face has a similar face opposite to it; and not only opposite to it, but in every position where a face is possible that is similarly situated with respect to similar axes. Similar faces, in crystallography, are those which are similar in relation to similar axes, though they may not be similar in size or form: and similar axes are those which are inclined to the other axes at equal angles, and the parameters measured on which are equal.

Crystals that present all the faces required by the law of symmetry just stated are called holohedral crystals. But in many cases only half the faces of a holohedral form, or half of some particular set of similar faces, are presented, the alternate ones being left out. Such forms are called hemihedral; the tetrahedron, for instance, is the hemihedral form of the octahedron. There is no instance of anything like hemihedrism among organisms.

Hemihedrism.

Another way in which crystals deviate from typical symmetry is by the production of hemimorphic forms. In these the two extremities of the crystal are of different

Hemimorphism.

forms, having unlike sets of faces, but within the limits of the same species, (that is to say, having the same crystallographic elements,) so that the two halves of the crystal seem as if they belonged to two different crystals. Hemihedrism and hemimorphism are characteristic of particular species.

Hemimorphism, which is occasional among crystals, is all but universal among organisms. Among plants and sponges there is a difference between the root and the upper part; and among animals generally, between the two ends of the alimentary canal.

Crystals repair injuries.

Crystalline growth is controlled in a very remarkable way by the laws of symmetry. Crystals have a power comparable, or rather identical, at least in its effects, with the power of organisms to repair injuries. Lavalle has found[1] that if a crystal of alum is placed in pure water till its edges and angles are dissolved away, and then put into a solution of alum, the edges and angles will form again. He also found that if one of the angles is cut off such a crystal, and the crystal put into the solution lying on the cut-off angle, so as to prevent that angle from forming again, a corresponding truncation will form, as the crystal grows, on the opposite angle.

Forms of crystals are modified by the medium they are formed in.

Crystalline formation is also dependent in a very remarkable way on the medium in which it takes place: and I intend farther on to show reason for believing that the same is true of some of the lower tribes of organisms. Beudant has found that common salt crystallizing from pure water forms cubes, but if the water contains a little boracic acid the angles of the cubes are truncated. And the Rev. E. Craig has found that carbonate of copper, crystallizing from a solution containing sulphuric acid, forms hexagonal tabular prisms; but if a little ammonia is added, the form changes to that of a long rectangular prism with secondary planes on the angles. If a little more ammonia is added, several varieties of rhombic octahedra appear; if a little nitric acid is added, the

[1] My authority for the statements in this and the following paragraph is Dana's Mineralogy, vol. i. p. 138.

rectangular prism appears again. The changes take place not by the addition of new crystals, but by changing the growth of the original ones.

Polarisation.

Most crystals, except those of metals and their alloys, are transparent; and most transparent crystals polarise light.

In what follows, I take the wave theory of light as proved: and it results from that theory that transparency, or the power of transmitting light, depends on optical elasticity, and that polarisation is caused by the optical elasticity being unequal in different directions.[1] It has been proved by mathematical reasoning on the laws of the propagation of luminous waves through media of unequal elasticity in different directions (or, as they may be called for brevity, unequally elastic media), that in every such medium there are three directions, at right angles to each other, in which the elastic force on which the propagation of the waves depends, reacts in the direction of the displacement. Two of these are also directions of maximum and minimum elasticity. These three directions are called the axes of elasticity, and are distinguished as axes of greatest, least, and mean elasticity.

Axes of elasticity.

In polarising crystals whereof the three crystallographic axes are at right angles to each other, the axes of elasticity are parallel to the crystallographic axes; but this, of course, is not the case where the crystallographic axes are not at right angles.

Ellipsoid of elasticity.

If now an ellipsoid is constructed with its three axes proportional to the three axes of elasticity, those diameters of the ellipsoid at right angles to which the sections of the ellipsoid are circles will be directions in which light passing along them will not be polarised: while light passing through the crystal in any other direction will be polarised. The directions of no polarisation are called optic axes.

Optic axes.

It follows from the properties of ellipsoids, that when the three axes of elasticity are all equal, the ellipsoid is a sphere; consequently all diameters

[1] My chief authorities for what follows on the optical properties of crystals are Dr. Lloyd, on the Wave Theory of Light; Pereira's Lectures on Polarised Light; and Mr. Maskelyne's Lecture referred to above.

are equal, the optical elasticity is the same in all directions, and no polarisation takes place. Such is the case in cubic crystals. Cubic crystals.

When two of the axes of elasticity are equal, and the third either greater or less, the ellipsoid is a spheroid of rotation, having the axis that is unequal to the others as its geometrical axis; the geometrical axis is the only axis the sections at right angles to which are circles, and consequently is the axis of no polarisation, or optic axis: a ray passing in any other direction is polarised. Crystals with these optical properties are called uniaxial. Uniaxial crystals.

When all the three axes of elasticity are unequal, the ellipsoid is not a spheroid of rotation: there are two diameters, at right angles to which the sections are circles, and which consequently are optic axes: these are not coincident with any of the axes of elasticity, but are in the same plane with the axes of greatest and least elasticity. Crystals with these optical properties are called biaxial. Biaxial crystals.

It is necessary to bear in mind, that the axes of elasticity and the optic axes are not *lines*, but *directions*; and that the ellipsoid by which the optical structure of a crystal is represented, though a true representation of facts, is imaginary.

After this brief account of the geometrical and optical properties of crystals, it is time to give some account of their classification. The classes, or systems, of crystals are distinguished from each other by the inclination of their axes, the equality or inequality of their parameters, and their optical properties. Systems of crystals.

In the cubic system, the axes are at right angles and the parameters equal: the optical elasticity is equal in all directions, and is represented by a sphere; they have, consequently, no polarising structure. Cubic system.

In the square prismatic system, the axes are at right angles; two of the parameters are equal, but the third is unequal to the other two. The axis of unequal parameter is called the vertical axis; it is an axis of symmetry for the crystal,—that is to say, the edges and angles Square prismatic system.

are arranged symmetrically around it, like the petals and other parts of a regular, or circular, flower around its axis.

Rhombohedral system.

In the rhombohedral system, the parameters are equal: the axes are not at right angles, but each of them is inclined to the other two at the same angle. There is an axis of symmetry, which however is not coincident with any of the crystallographic axes, but equidistant from the three; it is parallel to the line connecting those two opposite angles of the rhombohedron, which are similar to each other and unlike all the rest.

Optical properties.

In the square prismatic and rhombohedral systems, the optical elasticity is represented by a spheroid of rotation, with its axis parallel to the crystal's axis of symmetry: this is consequently the optic axis, and is the same in position for rays of all colours.[1] But for different colours it is generally, though not in all cases, different in magnitude; the physical interpretation of which is, that the amount of dispersion or angular separation of the rays in double refraction is different for rays of different colours.

Right prismatic system.

In the right prismatic system, the axes are all at right angles, and the parameters unequal. The axes of elasticity are parallel to the crystallographic axes, and, like the parameters, are all unequal: consequently the optical elasticity is represented by an ellipsoid which is not a spheroid of rotation, and there are two optic axes, neither of which coincides with any axis of elasticity. The axes of elasticity are the same in position for all colours, but different in relative magnitude: as a consequence of which

[1] We must apply some qualification to the statements in the text, that cubic crystals have no polarising structure, and that square prismatic and rhombohedral ones are uniaxial. Sir David Brewster has found that many cubic crystals have traces of polarising structure (Philosophical Transactions, vol. ciii.); and Professor Breithaupt has found most square, prismatic and rhombohedral crystals to be biaxial; but he is of opinion that this is due to want of symmetry in the crystals, and that the statements in the text (which are those made in all works on mineralogy) are true of perfectly formed specimens, which, however, are rare in nature. (Philosophical Magazine, June 1860.)

the position of the optic axes is different for different colours.

In the oblique systems, the parameters are unequal, and so are the axes of elasticity.[1]

Singly oblique system.

In the singly oblique system, two of the axes are inclined to each other (*i.e.* are not at right angles); the third is at right angles to the other two. To this third, or rectangular crystallographic axis, one of the axes of elasticity is parallel; but the other two axes of elasticity are not parallel to the remaining crystallographic axes, and are different in position for light of different colours: and, of course, the optic axes are also different in position for different colours.

Doubly oblique system.

In the doubly oblique system,[2] one of the axes is at right angles to the second, and inclined to the third; the second and third are inclined to each other. Its optical properties, so far as I know, have not been described, but they are no doubt similar to those of the system to be next described.

Anorthic system.

In the anorthic system, none of the crystallographic axes are at right angles to each other: the axes of elasticity are not parallel to them, and are different for rays of different colours, as are also the optic axes.

Crystals are classified on much the same principles as organisms. Among both, the species group themselves into genera, and the genera into classes or systems; among both there are varieties, which sometimes form a gradation between species: and among both, species or genera are found that form a gradation between classes.

Varieties.

As already stated,[3] crystalline varieties are due to slight differences in chemical composition: those which form a gradation from one species to another are due to the presence of plesiomorphous substances.

1 In strictness of language, the rhombohedral system is an oblique one; but it is not usual to call it so, as in its general properties it has more resemblance to the rectangular systems.

2 Only one species of this system has been described: it has been found by Naumann as the crystallizing form of an artificial salt. (Dana's Mineralogy.)

3 P. 69.

Boracite.

The most remarkable instance of a species intermediate between classes is that of boracite, which is geometrically one of the cubic system, but has the optical properties of a rhombohedral crystal: its optic axis is parallel to one of the diagonals of the cube.[1] There are also several instances of plesiomorphism between the cubic and rhombohedral systems.

Intermediate forms, showing the true affinities of the rhombohedral system.

In organic classification, the discovery of intermediate groups is often of great importance for the purpose of giving an insight into the true affinities of organisms and the true homologies of their parts. It is the same in crystalline classification. An important question, on which authorities are divided, is, what are the true crystallographic axes and the true fundamental form of the rhombohedral system. Those whom I have followed regard the fundamental form as the rhombohedron, and the true crystallographic axes as those lines which connect the centres of its opposite faces. Others call the system hexagonal instead of rhombohedral: they regard the hexagonal prism as the fundamental form, and the axis of symmetry of that form as the vertical axis; and they draw three horizontal axes in the same plane, at right angles to the vertical axis. The rhombohedron and the hexagonal prism are forms that are both found in the system; both, indeed, are found in the one species of calc-spar: and either may be derived from the other, in strict accordance with the geometrical laws of crystallography, by supposing the angles of the primary form to be truncated by secondary planes.[2]

[1] Pereira's Lecture on Polarised Light, p. 194.

[2] Brooke and Miller adopt the rhombohedral theory; Dana, the hexagonal one.

It may be said this is only a question of words, since either theory gives true mathematical results. I believe, however, that an inaccurate classification always tends to obscure knowledge.

In the text I have in some degree sacrificed accuracy to clearness and intelligibility. There is not strictly any such thing as a fundamental form; the only constant crystallographic elements are the inclinations of the axes, and the ratios of the parameters. In the cubic system, for instance, the cube and the octohedron may with equal accuracy be regarded as fundamental; and that system is called octohedral as often as cubic.

The hexagonal theory has the advantage of making the axis of symmetry, to which the optic axis also is parallel, to be a crystallographic axis.[1] But I believe the rhombohedral theory to be the sound one: partly because it makes no exception to the law that every crystal has three axes, and partly because, by referring the cube and the rhombohedron to homologous axes, it recognises the homology between the cubic and the rhombohedral systems, and the possibility of gradational forms between the two; while the hexagonal theory obscures these truths, by referring the cube and the rhombohedron to axes which are not homologous.

Affinities, true and apparent.

Among organisms the true affinities and homologies are not always the apparent ones: one organism may often be said to be disguised in the likeness of another. The whales, for instance, are mammals in the likeness of fishes: the chitons are molluscs in the likeness of annelids. The same occurs in at least one known instance among crystals.

Herschellite.

The crystals of Herschellite have the form of hexagonal prisms, which were formerly referred without hesitation to the hexagonal or rhombohedral system. But it has been found by examination with polarised light, by which the optical properties of crystals are tested, that the hexagonal crystal of Herschellite really consists of six triangular crystals, belonging to the right prismatic system; though they are not recognisable as such by their form, which is altered in consequence of their being thus united.[2]

Compound crystals:

This brings us to the curious and beautiful subject of compound crystals. These have been compared to animal monstrosities; but this is an error, or rather a stupidity, which has arisen from comparing crystals with the higher organisms instead of with the lower ones. The true analogy of such crystals as Herschellite is to flowers.

I prefer, however, to call it cubic, and so to keep before the mind's eye the homology betwen the axes of the cubic, rhombohedral, and prismatic systems.

[1] See p. 71 for the meaning of this expression.

[2] Dr. Von Lang in Philosophical Magazine, December 1864.

The occurrence of compound crystals is in some species only occasional, but in others, as in Herschellite, it is general.

Branching, Both crystalline and organic structures sometimes assume a branching form; as for instance in those combinations of ice-crystals called frost-work; in sea-weeds, in coral, and in trees. But this is characteristic of imperfect crystals and of low organisms. The ice-crystals that constitute frost-work do not present perfect crystalline forms, as is shown by their curved outlines. Sea-weeds and corals are low organisms; and though a tree is not so, the trunk and branches are less highly organized than the leaves and flowers.

Chain-like, Another mode of combination that belongs to comparatively low organisms, and, I believe, to imperfect crystals, is by a chain-like succession, as in the successive similar segments of worms, and in those molluscoids called Salpæ.

Double, "Twin crystals," or crystals found in pairs united by two of their planes, are common, and are characteristic of some species. Such a binary combination is not common among organisms, but it occurs in the calyx leaves of the poppy, and of that beautiful flower the dielytra.

Circular. Many crystals unite circularly round an axis. I have already mentioned Herschellite as an instance of this.

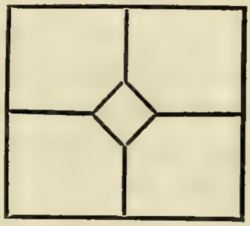
Snow. Snow consists of minute six-rayed stars, or, what is as good a description, six-leaved flowers, each of which is composed of six rhombohedral crystals.

Staurolite. And there is a species of right prismatic crystal called Staurolite, from the tendency of its crystals to unite into groups of four, shaped like a cross.

Resemblance to flowers. The resemblance of flowers to such crystalline forms as these is obvious: and it is a resemblance not only of form but of structure; for flowers consist of modified leaves arranged round an axis.

Interpenetrating crystals. Tetrahedral crystals of species belonging to the cubic system are sometimes found interpenetrating each other, in such a way that the middle part belongs equally to both. These cannot be compared to any normally compound organisms: they can only be compared to those monstrosities in which, for instance, one body equally belongs to two heads.

All crystals are of the same *chemical constitution* throughout: differing in this from organisms, in all of which, except the lowest, there is a difference of composition in the different parts. But in some crystals the *structure* is not the same throughout. Sir David Brewster has described[1] specimens of Apophyllite, a square prismatic crystal, consisting of crystals symmetrically united together, some of which, when examined by polarised light, prove to be uniaxial, and some biaxial: the optical character of each single crystal being in some way determined by its position in the compound one. One of the simpler forms described has a horizontal section like this: the central square prism being uniaxial, and the surrounding irregular ones biaxial. No difference of structure is discernible by any other means, and no joinings between the prisms are to be perceived. Tesselated Apophyllite.



Different parts of a crystal of Analcime have different optical structure. Analcime is a cubic crystal; but, unlike other cubic crystals, it has a very decided polarising structure: and, unlike all other known crystals whatever, it consists of parts that have different optical properties, not sharply separated as in the tesselated Apophyllites described above, but graduating into each other. If the cube of Analcime be dissected by planes passing through the twelve diagonals of its six faces, these planes will be found to be places of no polarisation. Every other part of the crystal polarises with a force proportional to the square of its distance from the nearest of those planes.[2] Analcime.

All perfect crystals have cleavage planes: that is to say, directions in which they split more easily than in other directions. This property of course depends on molecular structure. Cleavage planes are always parallel to faces which are possible ones in the species, and consequently faces artificially or accidentally produced by cleavage belong to the crystalline species as truly as those with which the crystal was originally formed. Cleavage.

[1] Edinb. Phil. Journ. vol. i. [2] Pereira on Polarised Light, p. 194.

CHAPTER VIII.

THE CHEMISTRY OF LIFE.

Organisms contrasted with crystals.

I HAVE stated in the last chapter, that the substance of crystals is *hard* and *impermeable* by water; that they grow by *superficial* accretion only, and are in a state of perfect *molecular immobility.* The substance of organisms, on the contrary, is mostly *soft,* and *permeable* by water; they grow by *interstitial* accretion only, and a certain degree of *molecular mobility* is the first condition of their life. An organism, so long as it lives, is constantly losing substance by excretion, or waste; and is constantly receiving new substance from without by accretion. Growth is due to the excess of accretion over waste.

Accretion and waste.

But the constant parting with old material and acquiring new material do not of themselves constitute life. If they did, a glacier would be alive; for it is constantly parting with material by melting away below, while it is as constantly acquiring new material in the shape of the snow that slides down to it above. The word *accretion* describes quite accurately the deposit of new material while a crystal is growing; but it is quite an inadequate description of the acquisition of new material by an organism. Only substances of peculiar chemical composition are capable of becoming part of the living organism. Consequently, only substances of suitable chemical constitution are capable of being food for organisms. So far, the organism resembles a crystal; for only the substance of which a crystal is formed, or some other substance which is isomorphous or plesiomorphous with it, can be added to the crystal and become part of its structure. But the difference consists

in this, that the new substance, in being deposited on the crystal, does not undergo any change whatever, except the change from the liquid to the solid state; while, on the contrary, no new substance can become part of an organism until it has undergone a certain transformation by the agency of the organism itself, which makes it similar in point of chemical constitution to the substance of the organism, and fit to become part of it. This process is what is called assimilation.

Assimilation.

The statement, that a living organism is constantly losing substance by waste and acquiring other substance by *accretion*, though true, is thus shown to be inadequate; and we must enlarge it by saying, that the organism is constantly losing substance by waste, and acquiring new substance *which it transforms into its own substance* by *assimilation*. This double process of assimilation and waste is general among organisms, vegetable as well as animal; and it has been very generally regarded as the only characteristic which is common to them all:[1] but I shall have farther on to give reasons for believing that there are other characteristics which are equally common to all organisms whatever.

Organic compounds:

The substance of an organism consists of chemical compounds of high complexity, which are not found in the inorganic world, but are formed by the action of the organism itself on the food that is brought from without. This process of forming the substance of the organism by assimilating the food is always going on; and the opposite process of waste is always going on, consisting in chemical changes that transform the compounds of which the substance of the organism consists, into compounds of simpler chemical constitution, which are no longer capable of forming part of the organism, but are excreted.[2]

[1] Comte (Positive Philosophy, Harriet Martineau's condensed translation, vol. i. p. 362) quotes with approbation De Blainville's definition of life as a "double interior motion, general and continuous, of composition and decomposition;" evidently meaning that life is a process of assimilation and waste.

[2] Even this statement may need some qualification. No doubt all organisms grow by assimilation, but it does not appear certain that all the

Every one knows that waste is constantly going on from animals. It is not so easy to prove that the same is true of vegetables, but it has been ascertained that vegetables, as well as animals, are constantly giving off carbonic acid,[1] which can only come from the waste of their substance.

is the distinction between them and inorganic ones absolute?

The statement made above, that the compounds which compose an organism can be formed nowhere but in the organism, will probably be questioned; indeed, many of my readers will probably think it is contradicted by those wonderful discoveries of late years in organic chemistry, which have made it possible to form many of the so-called organic compounds from their elements by the inorganic processes of the laboratory. The opinion appears to have gained ground, that there is no absolute distinction between organic and inorganic products, but that with increasing chemical knowledge we may hope to form in the laboratory every substance which we know as a product of vital action.

I believe it is.

I cannot, however, think so. The most characteristically organic, or vital, products are those of the albuminoid class; and I cannot think it possible that they can ever be formed by any chemistry except that of the organism of living vegetables. Animals cannot form them. All animals feed either on vegetables, or on other animals which have fed on vegetables; they receive the albuminoid compounds in their food; these undergo a process of assimilation in the animal's system, which makes them fit to be incorporated with its tissues.

If the albuminoid and other characteristically organic compounds could be formed by any inorganic chemistry, it would be possible for man and his domestic animals to

lowest organisms lose matter by waste. "In the process of putrefaction, the researches of Pasteur have shown that so far from oxygen being necessary to the life of the simple living beings concerned, there are certain forms of infusoria which not only pass their lives without oxygen, but are killed by its presence." (Beale's edition of Todd and Bowman's Physiology, p. 19.) What Pasteur here regards as infusoria must, I think, be rather vegetable than animal. But whether this is so or not, it is not easy to see how waste can go on in organisms that never come in contact with oxygen, and where, consequently, oxidation is impossible.

[1] Carpenter's Human Physiology, 6th edit. p. 8. It is from this edition I shall always quote.

obtain their food from chemical manufactories, and to be independent of the vegetable world; and this appears as far beyond possibility as it would be to create or destroy matter or energy by any physical process.

The truth on this subject appears to be, that the albuminoid class of substances, which are those which appear most essential to the vital processes of both animals and vegetables, can only be formed in, and by, an organism; and that those so-called organic products which have been made in the laboratory are not capable of forming part of any living tissue, but are only products of the decomposition of living tissue.[1] I do not say that they are all waste products. Urea, which was the first organic compound that was made in the laboratory, is no doubt a mere waste product. But this is not true of butyric ether, the flavouring matter of the pine-apple; amylic ether, the flavouring matter of the pear; and formic acid, which is produced by ants.[2] These have all been made in the laboratory, and yet they are not waste products: on the contrary, they are stored in the organism for purposes connected with its economy. But they are not capable of forming part of any living tissue. The truly organic compounds—those, I mean, which constitute the substances in which the vital processes go on—are *colloidal*, or gelatinous. Formic acid and the ethers, on the contrary, belong to the *crystalloidal*[3] class of substances, which may be solid and may be liquid, but cannot assume the intermediate gelatinous form; and though many of these, as for instance water, are necessary to life, they cannot become part of any living tissue—in a word, they cannot be *vitalised*—unless they enter into combination, and in so doing change their character.

[1] See Dr. Beale's edition of Todd and Bowman's Physiology, p. 9.

[2] See Quarterly Journal of Science, Jan. 1866, p. 36.

[3] I do not mean that they have been crystallized. But this is not the only test of crystalloidal nature. Only crystalloids have a strong flavour of any kind; and strong flavour is a characteristic of the substances mentioned in the text. This property is no doubt a result of their diffusibility in water, by reason of which they are able, when in solution, to come in contact with the extremities of the nerves of taste.

Life works through the chemical forces,

I have expressed my opinion, that it is in the nature of things impossible for the most characteristically vital products to be formed by any inorganic chemistry. I believe they are formed by the action of the ordinary chemical forces, modified and as it were guided by that of the vital principle. Life, or the vital principle, works not by opposing nor by suspending the action of the physical and chemical forces; on the contrary, it works through them. The relation of life to the lower forces may be compared, remotely but truly, to the relation of the mechanical engineer to the steam-driven machinery that he constructs and keeps at work; he does not set aside the properties of iron and the force of steam, but he avails himself of them, and works through them to the production of effects which the iron and the steam could not have produced of themselves.

as an engineer through a machine.

But even if it could be shown that the chemical actions that go on in the organism are no other than what can be imitated in the laboratory, it would still be certain that life is not a mere resultant from any physical and chemical forces, and that consequently there must be a distinct vital principle. By this expression I only mean that unknown and undiscoverable something, which the properties of mere matter will not account for, and which constitutes the differentia of living beings. To deny the existence of a distinct vital principle, in this sense, is not so much untrue as unmeaning. The formation of organic compounds is the lowest of organic functions, and is indeed characteristic of vegetables rather than of animals; above it are the functions of organization, instinct, feeling, and thought, which could not conceivably be resultants from the ordinary properties of matter.

The vital principle, defined.

But we must carefully guard against the error of setting up conceivableness or inconceivableness as a test of truth in questions of fact; and we must be equally careful not to make any assertion as to matter of fact, in the disguise of the definition of a term. Notwithstanding what I have said in the last paragraph, I freely admit that all questions concerning the origin of life are questions of fact, and

Origin of life a ques-

consequently must be solved, not by reasoning, but by observation and experiment. It is one of the most important of all scientific questions, whether the lowest forms of life can be generated by a purely chemical process. The preponderance of experimental evidence appears to be against any such possibility, and to show that no organism can be generated except from a previously existing organism. But if it could be proved that the lowest forms of life can be generated by a purely chemical process, still, as has been lately remarked, this would bring us no nearer to any absolute origin of life; for the chemical actions in which the lowest forms of life are by some believed to originate, consist in the decomposition of organic substances; so that even this would be a case of the production of life under conditions that require the previous existence of other organisms.—For these reasons it appears most probable that life, like matter and energy, had its origin in no secondary cause, but in the direct action of creative power.

tion for experiment.

Life had its origin in creative power.

The question of the origin of species is a totally distinct question from that of the origin of life.

Origin of species a distinct question.

There is good reason to believe the most important organic compounds to be thermo-positive.[1] "It has been recently shown by Berthelot that by the hydration and dehydration of organic substances heat results. Thus sugar, starch, and fatty matter by decomposition give rise to increased development of heat; and when albuminoid matters are hydrated and decomposed, or dehydrated and caused to enter into composition, heat is set free altogether independently of the process of oxidation."[2] It is, I think, quite impossible to interpret these facts except by supposing the substances in question to be thermo-positive; that is to say, that they contain a charge of energy which is due to their chemical constitution, and part with it when that constitution is subverted. Thus, energy is taken up, and stored, in the act of forming organic compounds; and this energy is liberated again, whether as heat or in some other form, in that chemical transformation which constitutes waste.

Organic compounds thermo-positive.

[1] See p. 50 for the meaning of this expression.

[2] Beale's edition of Todd and Bowman's Physiology, p. 137.

CHAPTER IX.

THE DYNAMICS OF LIFE.

Vegetables form organic compounds, which are oxidised by animals.

WE have seen in the last chapter that vegetables form the characteristically organic compounds; these serve as the food of animals, and, after undergoing an assimilative change in their nutritive systems, become part of their tissues. The organic compounds afterwards undergo a change, chiefly consisting in oxidation, which totally alters their chemical character, and makes them incapable of any longer forming part of a living tissue, so that they are cast out as waste materials.

Their actions are opposite.

Animals feed on vegetables, and vegetables feed on inorganic matter. That is to say, vegetables derive the carbon, hydrogen, nitrogen, and oxygen, which are found variously combined in their substance, from the carbonic acid, water, and ammonia of the atmosphere. The assimilation to which an animal subjects its vegetable food before that food can become part of its tissues, though of course it is an all-important process for the purposes of life, effects but a very slight chemical change, and an exactly similar assimilative process is necessary when the food consists of the flesh of other animals.

Animal assimilation.

So that we may broadly say, that vegetables form the organic compounds out of the materials of the inorganic world, and animals give them back to the inorganic world again, in the form of waste material. Thus the relations of vegetables and of animals to matter are opposite.

Their relations to energy are also opposite. As already stated, the change that converts the substance of animal tissues into waste material essentially consists in oxidation, and oxidation always produces heat, or some equivalent form of energy. The oxidation either of the food, or of the substance of the tissues that is passing away in waste, is the source of animal heat, and of the mechanical energy of animal motion. Animals thus *give out* energy to the organic world. The dynamical function of vegetables is the opposite of this. We have seen that they decompose water and carbonic acid. In the decomposition of water or carbonic acid, or any other product of combustion, a quantity of energy must be *taken up*, exactly equal to that which was given out when that product was formed by combustion; and this is true whether the decomposition is effected by an inorganic process, or in the organism of a living vegetable. Thus, whatever quantity of energy *becomes actual*, as heat, from the oxidation of the substance or the food of an animal, and is *given out* in the radiation from the skin and in the heated breath; the same energy must have *become potential*, and been *taken up*, when the vegetables on which that animal has fed[1] decomposed water and carbonic acid, and thereby fixed the combustible elements, the hydrogen and carbon of its food.

Opposite dynamic functions of animals and vegetables.

Animals give out energy.

Vegetables take up energy.

But in what form was this energy before it assumed this potential form? for vegetables cannot create energy out of nothing, any more than can animals or machines.

It was in the form of radiance. It is usually said that the leaves and other green parts of vegetables decompose carbonic acid *under the stimulus* of light. But this is an inaccurate expression: as well might we say, that the decomposing cell in electro-chemical experiments decomposes water *under the stimulus* of the electric current. The decomposing cell, and the green leaf, are alike only the apparatus where the decomposition takes place; the agent of the electric decomposition is the electric current, and the agent of the decomposition of the carbonic acid

Dynamic action of vegetables in decomposing carbonic acid.

[1] Or, in the case of a carnivorous animal, the vegetables on which its prey has fed.

(and, doubtless, water also) that is decomposed by the green leaf is the sun's radiance that falls on it. As the actual energy of the electric current is, in the act of decomposing water, transformed into the potential energy due to the mutual affinity of the separated oxygen and hydrogen; so the actual energy of the radiance that falls on a leaf is, in the act of decomposing the carbonic acid, transformed into the potential energy due to the mutual affinity of the separated oxygen and carbon.

Contrast of vegetables and animals.

Thus we see that vegetables transform energy from the actual state of radiance to the potential state due to the affinity of separated elements: and animals transform it back again into the actual state, either as heat, or as energy of muscular motion.

In a word, vegetables take up both matter and energy from the inorganic world, and the animals that feed on the vegetables give back the matter and the energy to the inorganic world again.

Vegetable respiration.

As already stated, however,[1] vegetables give out carbonic acid, the formation of which is due to the slow oxidation of their substance; and it is, no doubt, in consequence of this that, as ascertained by Dutrochet, their temperature while living is slightly higher than that of the surrounding air.[2] This is a process of respiration, essentially similar to the respiration of animals. Respiration consists in giving off the carbonic acid produced by the oxidation of the substance or the food of the organism: and oxidation is essentially combustion, and produces heat. Combustion is only rapid oxidation.

Organisms transform

It is no new discovery, but a familiar truth, that a transformation of matter is, as we have seen in the

[1] P. 86.

[2] Carpenter's Comparative Physiology, 3d edit. p. 846. It is from this edition that I shall always quote.

This fact shows that the energy which living vegetables transform, exists previous to its transformation, not in the form of heat, but in that of radiance. Were heat transformed and destroyed, healthy green plants would be sources of cold; but we have seen that the reverse of this is true. The coolness of vegetation as contrasted with the heat of bare earth or rock, in warm weather, is due to the fact that living plants radiate heat abundantly, and also produce cold by the evaporation of water from their leaves.

last chapter, constantly going on in every living organism. But I believe it is equally true, that a transformation of energy is also constantly going on; and I believe that any account of the vital process contains only half the truth, unless it gives as much emphasis to the fact of the transformation of energy by the action of the organism, as to the fact of the transformation of matter. In the present state of science, indeed, this is almost self-evident; but it could not be clearly seen until the laws of the conservation of energy, and of the transformations of energy, were understood. The principal relation of vegetables to energy is, as already explained, that they transform the radiance that falls on their leaves into the potential energy due to the decomposition of the carbonic acid which is separated into carbon and oxygen. And one important relation of animals to energy is that, as already explained, they produce heat by the oxidation of carbon, in their respiratory organs and throughout their whole system.

matter and energy.

Relation of vegetables and of animals to energy.

Animals produce heat

But it is obvious that this is not the only mode in which animals transform energy. They are producers of motion as well as of heat; and one of the most characteristic peculiarities of the animal kingdom as contrasted with the vegetable, is the possession of a special apparatus—the nervo-muscular—of which the primary function is the production of motion. But the production of motion does not depend on the presence of either nerves or muscles: there are animals of low organization, in which the microscope reveals no muscular structure, and indeed no structure at all, which have nevertheless the power of motion. And the same appears to be true of the "ciliated cells" of the higher animals.

and motion.

Motion independent of structure.

Heat and motion are the principal forms of energy that animals produce, but not the only ones. The glow-worm, and some other insects, have a special apparatus for the production of light, and many of the simpler marine animals are luminous.[1] And the torpedo, the gymnotus,

Animal heat, motion, light, and electricity:

[1] Among the medusæ and mollusca the luminosity appears to be due to a phosphorescent secretion, and, if so, cannot be regarded as a vital phenomenon. But among the marine annelids, or worms, it does not

and a few other fishes, have a special apparatus for the production of electricity at will; the structure of which, according to Professor Owen, very much resembles that of the muscles.

their origin

But motion, light, and electricity, as well as heat, can only be produced by the transformation of pre-existing forms of energy; and the usual statement is, that all the energy which animals transform and part with is due to the oxidation which, as we have seen, goes on within the organism. This statement however needs modification, for, as we have seen, the organic compounds, which undergo oxidation and decomposition in the organism, are thermo-positive;[1] and consequently energy is liberated in their decomposition, which no doubt becomes available for transformation into heat, muscular motive power, or any other form that may be needed for the purposes of the organism. But this we can say with perfect accuracy, that all the energy that animals transform has a chemical source, either in oxidation, or in the decomposition of thermo-positive compounds.

is chemical.

Does the animal organism store energy?

The question now arises, whether the energy that animals part with in muscular action is obtained, by these chemical actions, at the very moment when it is wanted; or whether there is a stock of energy constantly kept in the body, in a peculiar form distinct from any chemical form, and capable of being drawn on for conversion into muscular motive power when wanted?

This distinction may not be quite intelligible to readers who are not familiar with the subject of the transformations of energy; but it may be illustrated by the following example. When a steam-engine is at work in the usual way, the motive power that it exerts is all produced, by the combustion of the fuel in the furnace, at the very moment when it is wanted; and the steam-engine can do no more work in any given time than is due to the

Illustration from Armstrong's Accumulator.

appear in a steady glow, but in flashes or scintillations, which are produced by irritating the animal; and some of the smaller crustacea also emit light in little flashes. (Carpenter's Comparative Physiology, p. 841.)

[1] P. 89.

energy which is liberated in the combustion of the fuel that is burned in the furnace during that time. But if the steam-engine works in connexion with one of Armstrong's hydraulic accumulators,[1] energy, or motive power, is stored in the accumulator; so that work may continue to be done for some time after the steam is turned off or the fire put out. The question I have asked is this: Does the animal organism resemble the steam-engine working without an accumulator, which can only transform the motive power which is at that very instant liberated in the chemical process of combustion? Or does it rather resemble the steam-engine working with an accumulator, which stores motive power in a form that can be drawn on when wanted?

Vital energy.

I believe there is conclusive evidence that the latter is the fact. I believe there is conclusive evidence that the living animal contains a variable quantity of a peculiar form of static actual energy, which is capable of being transformed when needed either into heat or into muscular motive power. I propose to call this vital energy;[2] and I regard it as a distinct form of actual energy, just like heat, electricity, magnetism, or the energy of motion. An animal, regarded as a motor apparatus, may thus be compared to a steam-engine doing work with the assistance of an accumulator. In both, energy is being constantly obtained by the combustion of carbon (for the oxidation that goes on in the lungs and throughout the body is combustion, differing from that of a furnace only in being slower); in both, the energy, when not at the moment wanted to do work, passes into the static form. In the steam-engine it passes into the static potential energy due to the raised weight of the accumulator; in the animal, into that form of static actual energy which I propose to call vital energy. And in both, it is capable of being used as motive power when wanted to do work.

[1] P. 21.

[2] It will be perceived that *vital energy* is by no means a synonymous expression with *the vital principle.* If what I have endeavoured to establish on the subject of vital energy is proved to demonstration, it still leaves the mystery of the vital principle exactly where it was before.

But what is there in the organism to represent this vital energy? Heat and radiance consist in motion; magnetism and electricity, probably, in molecular tensions; but in what does vital energy consist?

Its nature inexplicable.

This question is at present impossible to answer, and perhaps must ever remain so. But the chemical forms of force are equally inexplicable. We cannot tell in what consists either the static potential energy that becomes actual in combustion or in the voltaic battery, or the actual energy that becomes static in the formation of peroxide of hydrogen, or any other thermo-positive compound.

I must now proceed to state the proofs of the existence of vital energy in a distinct static form.[1]

Of course I do not maintain that the whole of the energy due to the oxidation of the food, and of the waste materials of the body, is ever converted into vital energy. Probably by far the greater part of it, in all warm-blooded animals at least, is at once converted into heat, and used in keeping up the temperature of the body. It is a familiar fact, that whatever increases the activity of respiration, also increases the production of animal heat. But there are many phenomena of animal heat which are not capable of being thus accounted for. Though chemical action is the source of the heat as well as of the motor energy produced by the animal organism, no purely chemical theory will account for the local variations of temperature in the body.[2]

Muscular heat

Muscular action causes an increase of temperature in the acting muscle; and the increase is greater when the muscle is strained in a "dead pull" against something unyielding, than when it lifts a weight. This is a very interesting instance of the law of the *equivalence* of different forms of energy; the muscular energy which raises a

[1] The only author with whose work I am acquainted, that has distinctly asserted the existence of vital energy in a static form—or, in other words, asserted that the animal organism stores energy—is Dr. Norris, in his Report on Muscular Irritability (British Association, 1866, Nottingham). I had, however, thought out the whole theory of static vital energy independently.

[2] Paget, quoted in Carpenter's Human Physiology, p. 365.

weight is transformed into the potential energy due to the raised weight, and if the same muscular energy is expended without being able to raise a weight or do other external work, it is transformed into heat.[1] Normally, the increase of temperature is not more than about 1° Fahr., and it is not perhaps incredible that this should be due to the more rapid chemical action that goes on in muscle when it is in activity than when in repose. This heightening of chemical action in muscles during activity is proved by the fact that lactic acid, which is a product of their oxidation, is found in the muscles of animals that have been violently convulsed, though it is not found in muscles in their normal state.[2] But though chemical action may account for a rise of temperature in muscle to the extent of 1° Fahr. it appears altogether inadequate to account for a rise of the temperature of the body to 110¾° Fahr., which is more than ten degrees above its normal level; and this has been observed in the convulsions of tetanus. No conceivable increase in the rate of chemical action would produce such a rise of temperature as this; and I believe it must have been caused by the transformation of a portion of the stock of vital energy into heat.

in tetanus.

Another case of increased production of animal heat which cannot be due to any increase in the rate of oxidation or of any other chemical process, has been observed in patients dying of yellow fever, when the temperature of the body rose to the extent of 5° Fahr. in the first ten minutes after death. What proves, if proof were needed, that the heat could not be from any chemical source, is that the capillary circulation in those cases continued for an appreciable time after death, showing that putrefaction could not have set in; and this extraordinary production of heat can, I think, only be explained by supposing that the vital energy of the body was transformed into heat in the act of dying.[3]

Heat produced at death;

[1] The following statements, where no other authority is given, are taken from Carpenter's Human Physiology, chap. x.

[2] Carpenter's Human Physiology, p. 677.

[3] There is an experiment of the celebrated John Hunter which is

and during starvation.

Another proof that animals have a stock of vital energy to draw on for conversion into heat when needed, is afforded by the fact that starving animals are able for some days to produce heat at a greater rate than the chemical actions that go on in the body could supply.[1] For some days the temperature is kept very nearly up to its normal level, and afterwards it falls very rapidly; and the immediate cause of death is the depression of temperature. It is a familiar fact that starving animals lose substance, and it is certain that the oxidation of the substance that disappears helps to keep up the temperature; but it now appears that there is more heat produced than this will account for; and the excess can be, I think, due to no cause except the transformation of vital energy.

The vital energy in the body is of course not fixed but fluctuating in quantity; it is expended by muscular exertion, and restored again during rest, and especially during sleep.[2] Abundance of vital energy is probably the

probably a case of the same kind. He put a bottle containing leeches into a freezing mixture: a thermometer among the leeches sank to 31°; it afterwards rose to 32°, and the leeches froze. (Carpenter's Comparative Physiology, p. 848.) The thermometer rising when the leeches froze, seems to show that their vital energy must have been transformed into heat.

[1] "It has been experimentally found that in the ordinary life of an adult mammal, the quantity of food necessary to keep the body in its normal condition, is *nearly twice* that which would be required to supply the waste of the organism, as measured by the total amount of excreta when food is withheld." (Dr. Carpenter, Quarterly Journal of Science, vol. i. p. 265.)

It follows from this, that animals from which food is withheld are able to keep up their temperature, as starving animals do until they are near death, at an expenditure of *little more than half* the material (as shown by the amount of the waste of the body) that is consumed in well-fed animals. I do not see any possible way of doing this, except by drawing on their stock of vital energy for conversion into heat.

I presume that in the experiments referred to by Dr. Carpenter the "excreta" include the carbon that passes away by the lungs. Otherwise the experiments prove nothing at all, at least on the present subject.

[2] It is a general instinct among animals to keep themselves from external cold during sleep; and this may be in order to prevent the energy that they need for storing up in the muscular system, from being expended in conversion into animal heat, and employed in merely keeping up the temperature of the body.

cause of that feeling of buoyancy which makes action more agreeable than rest; and deficiency of it is probably the cause of the sensation of fatigue. And perhaps, though I only offer this as a suggestion, the immediate cause of death by fatigue may in some cases be the want of sufficient vital energy in the system to supply motive power for the muscular work of the heart and lungs.

Buoyancy and fatigue.

Death from fatigue.

It is the function of the muscles to transform vital energy into motor energy; and it appears to be one of the various functions of the nervous system to transform vital energy into heat. We may say, indeed, that the primary function of the whole nervo-muscular system, including the electric apparatus of the torpedo and other electric fishes, is to transform vital energy into other kinds of energy. To this class of phenomena probably belongs the well-known but little understood fact of the high temperature of inflamed parts. This cannot be due to any increase of chemical action; for, contrary to what we might expect, an examination of the blood that has passed through an inflamed part shows that oxidation goes on not more but less rapidly in an inflamed part than in a healthy one.[1] But the increased sensitiveness of inflamed parts shows that nervous action in them must be in some way heightened; and this heightening of nervous action probably determines a conversion of vital energy into heat. Sensation, however, is not what constitutes nervous action; sensation is only a concomitant of nervous action, and not by any means an invariable concomitant. The nervous system is primarily a part of the animal apparatus for the transformation of energy; and it is scarcely possible to doubt that all excitement of the nerves, whether accompanied by sensation or not, determines the transformation of part of the stock of vital energy into some other form of energy. If it is not transformed into motion, it is then probably transformed into heat. This is in accordance with the analogy of other vital actions; and, besides, there is something of the nature of experimental evidence for it. It is a familiar fact that severe pain often produces

Relation of the nervous system to animal heat.

Heat of inflamed parts

due to nervous action.

Insentient action.

Nervous action always causes transformation of energy,

[1] Beale's edition of Todd and Bowman's Physiology, p. 137.

sometimes into motion, involuntary convulsive struggles; and the stimulation of the motor nerves, unaccompanied by pain, is capable of producing the same effect.[1] In such cases the vital energy is transformed into motor energy. But vital energy is also capable of being exhausted in a perceptible degree by nervous excitement, even when there is no motor action; as is shown by the fact that the sense of fatigue is produced by mental exertion, or by pain unaccompanied by struggling, just as it is by muscular exertion. We should probably be justified in concluding, even without more direct evidence, that in such cases there must be a transformation of vital energy into heat. But there is direct evidence of such transformation. Valentin has obtained a rise of as much as $1\frac{1}{4}°$ centigrade in the temperature of the sciatic plexus of a frog, by mechanical or electrical irritation of its spinal cord.[2] It is quite impossible to say how far this was due to pain: or, we ought rather to say, how far it was accompanied by pain; for the physical character and results of nervous action appear to be exactly the same, whether it is accompanied by sensation or not.

sometimes into heat.

Valentin's experiment.

It is a remarkable proof of the dependence of nervous action on physical changes, that mental exertion causes the brain to lose phosphorus, which is found in the excreta.

I think I have given conclusive proof that nervous action is capable of producing heat and raising the temperature; and, conversely, a lowering of nervous action has a tendency to depress the temperature. The paralysed limb of a patient is usually somewhat colder than the healthy one. And a curious instance is on record, in which a wound of the wrist, which must have affected a nerve, produced partial insensibility in the forefinger, and lowered its temperature 10° Fahr. below that of the thumb.[3] These last two instances, however, only concern the local distri-

Paralysed limbs.

[1] As in those remarkable cases where the lower limbs have been deprived of sensation and voluntary motion by injury to the spinal cord, and yet have continued to respond, by convulsive kicks, to any such stimulus as that of tickling the soles of the feet.

[2] Medico-Chirurgical Review, January 1864.

[3] Carpenter's Human Physiology, p. 738.

bution of heat in the body; but we have evidence that the temperature of the whole body may be lowered by injury to the nervous system. It has been observed by Sir Benjamin Brodie, and by others who have repeated his experiments, that when the spinal cord of a rabbit or other animal is divided in the neck, and the action of the lungs (which otherwise would cease in consequence of the paralysis of the nerves that supply their muscles) continued artificially, so as to produce the normal quantity of carbonic acid, the temperature of the body falls. Now, we know that a definite quantity of actual energy is due to the formation of a definite quantity of carbonic acid by oxidation, whether in the living organism or in a furnace: in the experiment in question this energy does not appear as heat; what then becomes of it? I believe it is transformed into vital energy. I think the only possible interpretation of this experiment is, that the energy which becomes actual in the formation of carbonic acid by oxidation in the body, is in part transformed, not at once into heat but into vital energy, which the nervous system is capable of afterwards transforming into heat. Consequently, when the nervous system is in great part paralysed by cutting the spinal cord, the production of vital energy, which is a function of the whole organism, goes on as before; but its transformation into heat, which is a function specially of the nervous system, is hindered.

Effect of cutting the spinal cord.

I admit, however, that it is not generally a satisfactory mode of reasoning, to say that a particular solution must be true because it is the only possible one. We demand, and reasonably demand, more direct proof. In this case there is another experiment, which is the exact correlative of Sir Benjamin Brodie's, and shows us what has become of the energy in question. Brown-Séquard weighted the hind legs of living frogs, and thus ascertained what weight they were capable of raising when the muscles of the legs were excited to contract by pinching the toes: this weight was taken as the measure of the contractile force of the muscles. He then divided the spinal cords of the frogs, and found that twenty-four hours after the operation the

Experimental proof that the muscles store energy.

force of their muscles, as measured by the weight they were able to raise, was twice as great as when they were uninjured.[1] This, I think, when taken together with Sir Benjamin Brodie's experiment, affords direct and conclusive proof that in an animal with divided spinal cord the vital energy accumulates in the muscles, where it manifests itself by the greatly increased force with which they contract; while in an animal with uninjured nervous system, nervous agency determines the transformation of the vital energy into either heat or motor energy, and does not permit it to accumulate in so great a degree.[2]

It needs no proof that all animals produce motor energy. Most of them move about, and even those which are rooted, like corals and sponges, have tentacles or cilia, which they move. And, as we have seen, there is good reason for believing that animals have the power of storing vital energy, which they can afterwards convert into motor energy or into heat.

Motive powers of vegetables.

It is not so easy to prove that all this is true of vegetables: nevertheless I believe it is also true of them. The motion of the germs of sea-weeds is the most remarkable instance of motion in the vegetable kingdom: they move so actively through the water that they have often been mistaken for microscopic animals. But some degree of motive power appears to be universal in the "germinal matter" of vegetables as well as of animals.

"The substance called protoplasm[3] exhibits changes of form, and other movements, which cannot be explained by

[1] Dr. Norris's Report on Muscular Irritability, referred to in a previous note. Dr. Norris thinks, as I do, that this experiment proves that the muscles have the power of storing energy (or force, as he calls it).

[2] It is perfectly safe thus to reason from one organic species to another, for the fundamental laws of life are the same in all. Of course, this principle must be applied with caution; but as the frog and the rabbit agree in the general plan of the nervous system, and in having red blood-corpuscles, we are quite safe in assuming such an analogy between them as makes the two experiments comparable and parallel.

[3] Protoplasm is what Dr. Beale calls "germinal matter," and what I have called "unformed but formative material." The latter expression, however, is not suited to be a technical one, and I intend to call it "germinal matter." It is found in all living organisms whatever.

any physical property, or by any extraneous influences. These movements are most remarkably shown at times in the spaces of young cellular tissue. The movement termed rotation, or gyration, which is often seen in the contents of young cells, and which, in some form or other, is probably of general occurrence, may depend on the contractility[1] of protoplasm. They are said by those who have studied them to present a close resemblance to those of Amœba[2] and its allies. No one has yet shown a distinction of importance between protoplasm of the vegetable and sarcode of the animal kingdom. But there are other movements in plants, the cause of which is less equivocal. Such movements are not confined to the lowest plants, as the Oscillatoriæ, but are met with among the most highly organized members of the vegetable kingdom. The movements of sensitive plants, various species of Mimosa, of Dionæa muscipula,[3] of certain tropical species of Desmodium, of the stamens of Barberry, &c. can be referred only to vital contractility of certain of their tissues. Whatever obscurity may hang over these, let it be remarked that there is the same evidence of the nature of this vital contractility in plants as in animals. It is dependent on life, and not, like any physical property, retained so long as the structure itself is not destroyed. So, also, these movements either occur spontaneously, or may be excited by various stimuli—touch for example. If those motions depended upon elasticity, or hygroscopic changes, or any other physical cause which elsewhere operates, how could stimuli act to produce them? Moreover, they appear to be governed by the same laws that regulate their action in the animal kingdom. Their energy varies with the vigour of the plant. *Excessive exercise produces exhaustion, but the power is restored during subsequent repose.* This evidence, thus clear and satisfactory, receives a remarkable

[1] *Contractility* is not a good word. What is meant is only the tendency to spontaneous motion.

[2] The amœba is an animal, and one of the simplest known, being a minute gelatinous mass without structure.

[3] Familiarly called "Venus's fly-trap," from the way in which the leaves spontaneously close on flies and crush them.

and most interesting confirmation from the effects produced by the vapour of chloroform."[1]

Vegetables probably store vital energy.

I have italicised a passage in the foregoing extract, in order to direct attention to the fact that the motive powers of plants, like those of animals, are subject to the law of exhaustion by exercise and renewal during repose. This appears to afford a presumption, though it would be too much to say that it amounts to proof, that plants, as well as animals, accumulate a store of vital energy which is capable of transformation into motor energy when needed.

Relation of organisms to energy and to matter.

I believe we may consequently state, with very strong probability, that the relation of organisms to energy is parallel to their relation to matter. As an organism is constantly acquiring matter, which it transforms by assimilation into its own substance, so it is also constantly acquiring energy from the chemical actions that go on within its body, and transforming it into vital energy. This process may indeed be called the *assimilation of energy*;—energy, like matter, is transformed by the action of the organism into the peculiar form which the organism needs;—and this is the definition of assimilation. And as an organism is constantly parting with matter, which undergoes chemical transformation that unfits it for continuing any longer to form part of the organism, so it is also constantly parting with energy, which is transformed into inorganic forms (I mean, forms that may exist independently of vital agency); generally into heat or energy of motion: in the case of electric fishes, into electricity; in the case of luminous insects, into radiance.

Energy is assimilated.

We may consequently make the following general statement.

General statement.

An organism consists of a mass of peculiar chemical compounds of high complexity, and contains a charge of a peculiar kind of static actual energy. It is constantly transforming both matter and energy, by assimilation, into those peculiar forms: and is as constantly parting with

[1] From a lecture "On Motion in Plants and Animals," delivered at the Royal Institution on 14th March, 1862, by William Scovell Savory, F.R.S. See also Beale's edition of Todd and Bowman's Physiology, pp. 33, 99.

matter and energy, which are transformed into forms that are no longer capable of remaining in the organism. These relations of the organism to matter and energy constitute, I believe, the differentia of life; and death consists in the organism losing that peculiar power of controlling the action of the chemical and physical forces in virtue of which it transforms and assimilates matter and energy.

Death followed by chemical transformations.

When death has taken place—or, in other words, when the controlling vital principle has ceased to act—the chemical forces begin to act according to their own ordinary laws, and decay or putrefaction may result, as circumstances determine. In many cases, indeed, where death takes place slowly, a change of the nature of putrescence begins before life is extinct.[1] It would be altogether inaccurate to say that the action of the vital principle during life suspends the action of the ordinary chemical forces; on the contrary, the process of oxidation, causing the transformation of organic compounds into inorganic ones, probably goes on more rapidly in the body of a warm-blooded animal during life than it does in the same during the process of decay after death. But of course the waste is balanced by assimilation of food in the living animal, and not in the dead one. Vitality, I say, does not suspend, but directs and controls, the actions of the physical and chemical forces, producing results through them which they could not have produced of themselves.

Chemical action during life.

I have already stated that I believe organisms have a relation to energy, parallel to their relation to matter. We have seen that as a result of death the chemical forces, being freed from vital control, act according to their own ordinary laws, and effect the transformation of the organic chemical compounds into inorganic ones. In a similar way, death, as I believe, effects a transformation of vital energy into some ordinary inorganic form of energy. I have mentioned an instance in which the vital energy appears to have been transformed into heat in the act of dying. But its transformation into motor energy is perhaps a commoner case. This is, I believe, the *rationale* of those

Transformation of vital energy in death

[1] See Carpenter's Human Physiology, p. 57.

convulsive struggles that often accompany death, and which are usually attributed to pain, though this is not by any means invariably true.

and in disease.

Disease appears sometimes to effect in part the transformation of energy which death effects totally. Inflammation is a diseased state, and, as we have seen, in inflamed parts there appears to be an unusually rapid transformation of vital energy into heat. The rise of temperature in tetanus is another case of the same transformation, though the manner in which it is effected is probably very different.

Analogy of life to magnetism.

We may compare the charge of static actual energy, which, as I believe, every living organism contains, to the charge of static actual energy, which, as I think I have shown, constitutes magnetisation. As only some substances, all of which are metallic, are capable of being magnetised,[1] so it is only some substances, all of which are highly complex compounds of the albuminoid class, that are capable of being vitalized: and as magnetised iron is able to communicate magnetism to other iron, so vitalized matter is able to vitalize other matter of suitable chemical constitution which has become the food of an organism. Thus the laws of magnetism resemble, and as it were prefigure, those of vital energy, as the laws of crystallization resemble, and as it were prefigure, those of organization. But an organism differs from both a crystal and a magnet in this, that so long as the organism lives it is constantly assimilating, and again parting with, both matter and energy.

Summary.

The most important conclusions of this chapter may be thus summed up:—

Organisms assimilate, store, and finally transform and part with, energy as well as matter. The primary function of the nervo-muscular system of animals is to effect the

[1] Faraday has shown that oxygen is magnetic, but I do not think this implies that gaseous oxygen is capable of being magnetised. Magnetisation, as Faraday has shown, implies lines of force in definite directions, such as, I think, can only be due to the molecular tensions of solid bodies. See note to Chapter III.

final transformation of vital energy into inorganic forms of energy, especially into motion, in many cases into heat, sometimes into light or electricity. Muscular action transforms vital energy generally into motion, nervous action generally into heat. The muscles have the power of storing energy, in a peculiar static form, for future transformation. At death all the vital energy that was stored in the organism is transformed into inorganic forms: always, probably, into either heat or motion.

I am perfectly well aware that in this chapter I have not given a full account of the relation of energy to the various vital processes. But it is probably impossible to do so as yet. There appears to be a demand for energy in the form of heat, and probably a transformation of it, in the process of organic development. Heat, as already stated, appears to be a concomitant of vegetable as well as of animal life generally: and heat is produced in unusual abundance in the act of flowering,[1] and again in the germination of the seed. Its source in these cases is oxidation: this is proved, if proof were needed, by the production of carbonic acid: and its purpose, no doubt, is in some way to promote the transformations that take place in the acts of flowering and germination. Animal development also depends in some way on temperature: this, as every one knows, is true of the hatching of eggs, and it is equally true of the final metamorphosis of the insect.[2] It is a case of the same law, that the triton, or water-newt, which has a remarkable power of reproducing lost limbs, can only do so at a higher temperature than that which is necessary for its health.[3] It is scarcely possible to doubt that, in every act of organic development, there is *some* transformation of energy, though we cannot yet say *what* transformation. Perhaps a charge of energy is taken up

Dependence of development on heat.

Transformation of energy in organic development.

[1] Adolphe Brogniart found the flower of the Arum cordifolium 20° of temperature above the surrounding air. (Carpenter's Comparative Physiology, p. 846.) It is not stated whether the degrees are centigrade or Fahrenheit's. 20° C. = 36° F.

[2] Carpenter's Comparative Physiology, p. 849.

[3] Ibid. p. 65, quoted from Mr. Higginbottom: Proceedings of Royal Society, 18th March, 1847.

and becomes static, in the act of unorganized material acquiring organization.[1]

Energy of life depends on the supply of oxygen.

Vital processes go on with the greatest energy where oxidation is most rapid. This is partly, no doubt, because oxidation yields the necessary supply of heat and other forms of energy: partly also, because the waste, or what may be called the wearing out, of the tissues of the organism goes on most rapidly where vital processes are most energetic: and this will soon be checked if there is not a supply of oxygen to transform the organic compounds into freely soluble compounds, which can be easily removed from the system. It is, no doubt, in consequence of these two causes that air-breathing animals and air-breathing plants are in general, and on the average, of much higher organization than water-breathing ones, and that air-breathing animals have a more active and energetic life, for air contains a much more abundant supply of free oxygen than water. Warm-blooded animals, which stand at the head of the whole animal kingdom, are without exception air-breathers: and, among vegetables, most of the water-breathing kinds are flowerless, and, as such, inferior to the flowering ones in organization. It is no exception to this, but rather a confirmation of it, that many flowering plants, such as the water-lilies, though rooted under water, raise their flowers and part of their leaves into the air, in order no doubt to enable them to obtain the oxygen they need. It belongs to this class of facts that there are many instances, among both insects and batrachians (frogs, newts, and similar animals), in which the larva is a water-breather and the perfect form an air-breather; but not a single instance, I believe, of the converse: for the perfect form in those two classes is always more highly organized than the larva. It is indeed the general law of animal metamorphosis, though subject to some remarkable exceptions, that the mature form is more highly organized than the larva.

The most highly organized plants and animals are air-breathers.

Larva and perfect form.

[1] See chap. i. of Carpenter's Human Physiology.

NOTE.

ON THE RELATION OF MUSCULAR ACTION TO HEAT.

We have seen that in muscular contraction heat is produced; and this I believe to be, in part, transformed vital energy. (I say *in part*, because I have no doubt that it is in part also due to the chemical action that takes place in the muscle at the moment.)

Cold produced in muscular action.

But it has been shown by careful experiments on frogs, that the first effect of muscular contraction is a slight cooling.[1] The most probable explanation of this fact appears to be, that the commencement of muscular action causes the conversion of a small quantity of heat into muscular motor energy.

There is a remarkable fact in inorganic dynamics, which is nearly parallel to this.

Parallel fact in thermo-electricity.

If a joint formed by soldering bismuth to antimony is heated, an electric current will flow through the joint from the bismuth to the antimony. This depends on the unequal powers of the two metals as conductors of heat.

If a current *from an external source* is sent through the joint from the bismuth to the antimony (consequently in the same direction as the current that would be produced by *heating* the joint), the joint will be *cooled*. If the current is sent through the joint in the opposite direction, the joint will be heated.[2]

The only possible explanation of the cooling of the joint is, that the passage of the electric current through it determines the conversion of part of its heat into electricity; and this is analogous to the commencement of muscular action determining the conversion of part of the heat of the muscle into muscular motor energy.

These cases are exceptional.

Both of these cases are exceptional. They are, I believe, the only known instances of the conversion of heat into any other form of energy being caused by the passage of a current of that other form of energy.

[1] Solger, and Meyerstein and Thiry, quoted in the Medico-Chirurgical Review, January 1864.

[2] Tyndall, in the Philosophical Magazine, December 1852.

CHAPTER X.

ORGANIZATION.

Three kinds of formative principles;

THERE are in nature three kinds of formative principles, each of which produces its own characteristic forms, totally unlike those of the others.

the first forms spherical aggregations.

All forces which are simply attractive produce spherical forms. Gravitation and capillarity are forces of this class: a planet, which owes its spherical form to gravitation, and a rain-drop, which owes it to capillarity, are both instances of this kind of formative principle. In such aggregations there is not necessarily any structure: a rain-drop has no structure: and when there is any, it consists merely in stratification; that is to say, in the deposition of layers of substance round the centre of the sphere. An agate nodule is a good instance of this: every one is familiar with the beautiful markings, approximating in form to concentric circles, which are presented when the spherical nodules of agate are cut through and polished, so as to show their structure, and which are due to the nodule consisting of concentric layers stratified round its centre. Whatever may be the kind of force to which the formation of these nodules is due, whether it is only capillarity acting under special circumstances, or some quite peculiar species of force, it is evidently a simply attractive force like gravitation or capillarity, and not a polar force like that of a magnet.

Agate nodules,

having structure depending on form.

It is evident also that the structure of the agate nodule depends on its form, and not the converse. The relation of structure to form, indeed, consists in this, that the solid sphere is composed of a number of concentric hollow

spheres. It may be worth mentioning that hailstones have been found with a structure like this, or, to use a more familiar though less really apposite comparison, composed of coats like those of an onion. This structure is probably due to their being attracted and repelled back and forwards between two oppositely electrified clouds, like the pith balls used in electrical experiments.

Hailstones.

The second kind of formative principle is that to which the form and structure of crystals are due. This is different from the former, and much more complex. It is evident that the force which brings the particles of a salt or other crystallizing substance together from the water in which it is in solution, must be an attractive force. But it is not *simply* attractive. A simply attractive force, when acting alone, can, as already remarked, produce none but spherical forms. It is, in the largest sense of the word, a *polar* force; that is to say, a force that acts differently in different directions: for crystals are never spherical, but are, when normally formed, always bounded by plane surfaces. There is also this difference, that in spherical forms the structure, when there is any, depends on the form; but in crystalline forms the form depends on the structure. This, as to crystals, may need explanation. In crystallization the essential point, as stated in the chapter on that subject, is not the form, which is variable for the species, but the relation between the axes, which is constant, and which constitutes the structure; and any form is possible in a species if the angles at which the planes are inclined on each other are such as to be consistent with the relations between the axes of that species. The dependence of form on structure may be thus experimentally illustrated. A mineralogist finds a lump of some mineral substance that presents no definite form; but from its lustre, or some other characteristic, he suspects that it is crystalline; and by a few properly-directed blows of his hammer he breaks it in the direction of its cleavage, splitting it into large fragments bounded by faces which are parallel to the cleavage planes, and make angles on each other that are consistent with the relation between

Second kind, producing crystals,

having forms depending on structure.

the axes of the species. A form thus obtained, depending on cleavage, is as truly a natural one as if it were obtained simply by picking it up; and it manifestly depends on structure, of which cleavage is one of the most important expressions.

Third kind, producing organisms.

The third kind of formative principle is that of vital organization, to which the forms and structures of organisms are due. The organic formative principles probably transcend in complexity those which form crystals, almost infinitely more than those which form crystals transcend those which form spheres. Concerning the formation of spheres there is no mystery whatever. Gravitation, and every other primary force and ultimate property, are no doubt inexplicable; but, if we take the force as a datum, it is self-evident that a force which is simply attractive must tend to produce aggregations of spherical form. Concerning the formative principles of crystallization we know very little as yet; but it does not appear beyond the powers of man's intellect to find mathematical expressions for the complex polarities that determine the characteristic structure and form of every crystalline species, and even to discover their physical laws.[1] But it never can be possible to give any mathematical statement, or any physical explanation of those mysterious formative principles in virtue of which the structureless and homogeneous germ of an organism acquires definite structure, and separates into distinct organs.

Organization inexplicable.

It needs no proof that in the case of spheres and crystals the forms and the structures are the effect, and not the cause, of the formative principles. Attraction, whether gravitative or capillary, produces the spherical form: the spherical form does not produce attraction. And crystalline polarities produce crystalline structure and form: crystalline structure and form do not produce crystalline polarities.

[1] See the chapter in Dana's Mineralogy on "Theoretical Crystallogeny." Also an article by the same author in the Philosophical Magazine, September 1867, on the connexion between chemical constitution and crystalline form.

Life is the cause of organization.

The same is not quite so evident of organic forms, but it is equally true of them also. Organic form and structure are the result of the organic formative principle; or, in briefer words, life is the cause of organization: organization is not the cause of life. Organization is not essential to life: it is not the differentia of living beings. The differentia of living beings consists, I believe, in those peculiar relations to matter and energy which have been explained in the last chapter: organization is only one of the most general and most important results of life.

Organic germs are without structure, as are some mature organisms.

The proof of this is, that while, as every one will admit, there can be no organization except where there has been life, there may be, and is, life where there is no organization. It is an observed fact, independent of any inference or any theory, that life exists prior to organization. The germs of organisms are not miniatures of the perfect form, nor are the perfect forms produced from the germs by any process that can be properly described as unfolding: on the contrary, the germs are without structure and without definite form, and have no character whatever, whether chemical or microscopic, by which the germ of one organism can be known from that of another, however unlike the species may be.[1] This fact, that all organisms are developed out of perfectly simple germs, is, from a purely scientific point of view, probably the most important of all the discoveries of modern physiology. But though without structure, the germ assimilates matter and grows, thus showing that it possesses the characteristically vital properties with respect to matter, and probably with respect to energy also.[2] In all but the very lowest classes of organisms, the germ, as it grows, acquires structure and organization. But it is a most significant fact, that some of the lowest animals (of which the amœba is probably the best-known type) never acquire any structure whatever, or any constant form: they continue to be mere minute gelatinous masses, which however exercise those

[1] Carpenter's Comparative Physiology, p. 25.

[2] See the preceding chapter. It is to be regretted that we have no single word for *living being* except *organism*, a word which suggests the untrue notion that organization is the essential point in life.

Germinal matter has no structure.

nutritive and motor functions that show them to have the characteristically vital relation to matter and energy. And the "germinal matter" of organisms, previous to its transformation into their "formed material," is without structure, though it has in the highest degree what I regard as the characteristically vital properties.

Crystallization and organization.

It needs no proof that the unformed but formative material of a crystallizable substance (as, for instance, a salt while in solution) has a constant tendency to assume the form and structure of the crystalline species, and does assume it when circumstances favour. The same is true of the unformed but formative material, or "germinal matter," of organisms; the germinal matter of every organic species constantly tends to assume the form and structure of the species to which it belongs. Hence is the power of a germ, when placed under favouring circumstances, to transform itself into the perfect form of its species. Hence (what is essentially the same property) the power, among many plants and among the lowest animals, of a cut-off part to transform itself into a perfect individual. And, what is only a lower degree of the same, the power of repairing injuries, which all organisms possess in a sensible degree, and which has been observed also in crystals.[1]

Reaction of formed on unformed material.

In organisms also, as in crystals, the formed material reacts on the properties of the unformed but formative material. The strongest instance of this is the sympathetic reproduction of injuries, which, as we have seen, occurs in crystals[1] as well as in organisms, and is due to the formed material, which has suffered the original injury, modifying the further action of the formative material.[2]

But what is organization? and how does organic structure essentially differ from crystalline structure?

[1] P. 75.

[2] Dr. Beale speaks of different kinds of germinal matter. But notwithstanding my high respect for his scientific attainments and scientific services, I submit it is much more likely that there should be only one kind of germinal matter in each organic species, and that this ministers to the growth of whatever tissue it occurs in. This view is supported by the fact, that the smallest portion from any part of an hydra, or other such low organism, will reproduce the entire form belonging to the species.

The most obvious answer to this question perhaps would be, that the structure of a crystal is alike throughout and in every part, but that of an organism is different in different parts; the leaves and the wood of a tree, for instance, are of different structure, and so are the bones, the muscles, and the nerves of an animal. But we have seen that though crystals are generally perfectly alike in structure throughout, there are some perfectly regular crystals, which, when they are examined by the infallible test of polarised light, show a difference of structure between their different parts.

Organization defined.

The essential difference between organization and any kind of inorganic structure is quite different from this: organization is the adaptation of structure to function. This principle, of adaptation of structure to function, and of one structure and one function of an organism to another, is characteristic of the organic creation, and is utterly unlike anything that we meet with in the inorganic world.

Three relations in science: Cause, Resemblance, Purpose.

There are three principles of logical relation, that run like guiding threads through physical science. These are—

1. The relation of cause and effect;
2. The relation of resemblance and difference; and
3. The relation of means and purpose.

For the sake of brevity let us call these cause, resemblance, and purpose. Of course I do not offer this as a complete enumeration of all possible relations: I well know that it is nothing of the kind. I only say that, as a matter of fact, these are the most important relations that we meet with in the physical sciences.

Sciences of cause.

The relation of cause is almost the only one that the dynamical sciences have to do with: under which title I include not only general dynamics, but the sciences of sound, radiance, heat, electricity, and magnetism; which are all now recognised as special cases of dynamical theory. And the same is, in a great degree, true of those more elementary branches of chemistry that have to do with the general properties of matter, and with the relations of composition and decomposition to heat and to electricity.

Chemistry.

The general problem of this whole group of sciences is to infer causes from effects and effects from causes.

But in the higher or more complex chemistry, especially in the chemistry of organic compounds, the known and possible combinations are so many, and the variety of interactions is so great, that in the present state of science it is impossible to do for chemistry what we have been doing since Newton's time, and are still doing, for the dynamical sciences; namely, to refer the multitude of phenomena to a few causes, of which the phenomena are effects.

Every science, however, must have some principle, or principles, of logical relation; were it without any, it would not be a science at all, but only a mass of unconnected facts. In chemistry, this very multiplicity, variety, and complexity of the facts, which places any knowledge of their causes at present beyond our reach, supplies us with a new principle of scientific relation: that of resemblance. Compounds are not formed without relation to each other, or as it were at random; they are formed in series, and in series of series; and this relation is most decided in the higher or more complex chemistry. Chemistry, in its higher branches, has thus become a classificatory science; and the most important result which has been yet achieved in the higher chemistry consists in the establishment of the theory of types and substitutions, by which a rational classification of the vast multiplicity of compounds has been made possible.

Sciences of resemblance, or classificatory sciences.

Crystallography.

Crystallography also is a science in which causes are as yet almost totally unknown. We know little or nothing of the causes that determine crystalline formation; we can only describe and classify crystals by their chemical, geometrical, and optical properties. Crystallography, or the science of crystallization, is thus a classificatory science. We have seen that chemical compounds are formed in series, and in series of series. Crystalline species exist in groups, and in groups of groups; or, to use technical language, in genera and classes.[1]

[1] The difference between a series and a group is, that the names of the members of a series can be properly enumerated in only one order, those

A very large part of biology, or the science of life,[1] consists, like crystallography, in the description and classification of the forms of various species. Organic species, like crystalline species, exist in groups, and in groups of groups. The description of the forms, both in crystallography and in biology, constitutes morphology; and the determination of the fundamental relations (which are not always the obvious ones) between the forms is the problem of classification. Biology, like crystallography, is thus a classificatory science. Biology. Morphology.

It appears to be the opinion of many, that questions of classification are merely questions of names, and consequently of no true scientific importance. They think that the expression *true* classification is without meaning, and that a classification will serve every purpose that it possibly can serve, if it is only generally agreed on, so as to prevent confusion in the use of names; and intelligible, so as to make reference easy. According to this view, the question whether a whale is a fish or a mammal, and whether a barnacle is a mollusc or a crustacean, are questions of words only, not of realities; though some words or names may be more conveniently applicable than others.

The fallacy, or rather the inadequacy, of this notion is not easy to prove in any demonstrative form: and it must suffice here to assert, that every one who has experience of the study of any science whatever to which the classificatory method is applicable, becomes convinced, if he was not so at the commencement, that true classification is one of the greatest possible helps to knowledge, and inaccurate classification one of the greatest possible hindrances. Importance of classification.

True classification may be defined as classification according to the resemblances and differences of the *funda-* Its basis in funda-

of a group may be enumerated in various orders. The different oxides of a metal, for instance, which are formed by the successive addition of equivalents of oxygen, form a series.

[1] I intend to use this word throughout. We need a word that shall apply to the life of animals and of vegetables alike, and that shall include both morphology, or the science of organic forms, and physiology, or the science of vital functions. I do not know who first coined the word, but it is used by Comte in his Positive Philosophy.

mental characters. No rule possible. *mental* characters of the things classified. But no definition of fundamental characters is possible; or, in other words, there is no possible rule or formula, applicable to all cases alike, for determining which of the characteristics of a thing are the really fundamental ones. The only approximation to such a rule is, that the fundamental properties must be those on which the other properties depend: this is true, and indeed self-evident; but our knowledge of the way in which the various properties of the same thing are related to each other is too limited for us to be able to apply this principle as a rule. The manner in which the colours of substances depend on their chemical constitution, for instance, is a subject of which we know nothing, and probably shall never discover anything. We can only lay down this negative rule, which is however of great importance, that the obvious characteristics are not necessarily, nor generally, the fundamental ones.

But though it is impossible to lay down general rules which shall be applicable to all sciences alike, for the ascertaining of the fundamental characters, and the consequent establishment of a true classification; yet, in the case of every particular science, these are ascertained as a necessary result of the progress of the science; and when the fundamental characters have been ascertained, and when the true principles of classification, applicable to that science, have been thus established, this reacts most favourably on the further progress of the science.

Fundamental characters in chemistry, In chemistry, the most obvious properties of substances are those dependent on their usual state of molecular aggregation, solid, liquid, or gaseous. But the fundamental properties are those of chemical composition; or, in simple substances, those of chemical relation to other substances.

crystallography, In crystallography, the fundamental characteristic is not the form, but those relations between the axes (technically called the crystallographic elements) on which the form depends.

and biology. In biological classification, the fundamental characteristics on which the true classification of a species or of

a group depends, are determined by the "law of development" in a way that is altogether peculiar to biological science, as I shall have to explain farther on.

But the description, comparison, and classification of organic species—that is to say, organic morphology—constitute only one-half of the science of biology, and that its least characteristic half. Crystals, like organisms, have their morphology and their classification; but in crystals there is nothing but structure to consider: there is no adaptation of structure to function, because there is no function. Function (in the organic, not the mathematical sense) is impossible and inconceivable in such bodies as crystals, which can continue to exist only under the condition of perfect molecular immobility, and cease to be crystals if this is disturbed. In organisms, on the contrary, every structure is adapted to its function, and structure depends on function. Consequently, the second, and most characteristic part of biology, consists in physiology, which is defined as the science of organic functions, and of the relations of structures to their functions.

Morphology.

Physiology.

I call physiology the most characteristic part of biology, because, by the definition, physiology alone takes cognizance of that relation of structure to function, or, what comes to the same thing, of means to purpose, which is peculiar to the organic creation. We have seen that the relation of cause and effect is the characteristic relation in the dynamical sciences, and that of resemblance and difference is the characteristic one in the classificatory sciences. Biology is a classificatory science; but the relation of means and purpose is also a characteristic one in biology, and is found there alone.

From this point of view, we may say that morphology is the classificatory side of biological science, and physiology its functional side.

I may be told, that when I say that the relation of structure to function is the same thing with the relation of means to purpose, I am assuming as true an hypothesis which has not been, and cannot be, verified.

I reply, that the relation of special structure to special

Purpose in creation peculiar to organization: has analogies in man's work.

function, as for instance the relation of the structure of the eye to the function of vision, is something which has no analogy whatever in the inorganic creation, though it has analogies in machinery and other apparatus of human invention. The analogy of the eye to the camera obscura is a case in point; in fact, the eye is a camera. And in speaking of such organic adaptations, we naturally and almost inevitably fall into the habit of regarding special function as a proof of purpose; and of speaking of the function of an organ and of its purpose, as if the words were synonymous: and this habit is not found to be misleading; on the contrary, it is a rule in physiological research (though subject to a few very remarkable exceptions), that every organ, and every structural arrangement, must have its own special purpose. These are facts, very much generalized no doubt, but still facts of observation, concerning which there is no room for doubt or controversy.

Organic structure implies function.

But when it is denied that there is any discernible purpose in the organic creation, the meaning appears to be, that the relation of special structure to special function, or what I have called the relation of means to purpose, is in reality only a particular case of the relation of cause and effect. It would be impossible for any man of the slightest intelligence, simply to deny the existence of the most wonderful special adaptations in the organic creation. But though not a plausible doctrine it is an arguable one, and has been maintained with great knowledge and great ability by Darwin in his "Origin of Species," and by Spencer in his "Principles of Biology," that the laws of cause and effect are adequate to account for all these; that the adaptation of the eye to light, for instance, has been *produced* by the direct and indirect action of light on countless generations of living beings: and so of all other organic adaptations.

Is this relation a case of that of cause and effect?

I believe not.

From this theory I utterly dissent, and in a future chapter I shall give reasons which I regard as conclusive against it. I believe that the relation of means and purpose in organization is as much a primary law of nature, and as incapable of being resolved into any other more

general principle, as the relation of cause and effect. I will here only remark, as a presumption against the theory in question, that as we ascend in the scale of nature to higher and higher vital functions, and higher and higher organic forms, we find the relation of cause and effect becoming less traceable by our faculties (though no doubt it exists all through nature); while at the same time the relation of means and purpose becomes at once more traceable and more definite. Nowhere in the universe as known to us, is the relation of means to purpose more clearly traceable and more perfectly definite, than in the organs of special sense in the higher animals, especially in the eye and the ear; and nowhere is it more difficult (I would say, utterly impossible) to assign any physical cause for the facts, as when we inquire by what cause, or by what agency, such wonderful organs have been formed. And as we ascend in nature, not only do the separate functions become more traceable, but their mutual relations become more definite. The trunk, the leaves, and the flowers of a tree, for instance, have each their function, but it would be unmeaning to ask whether the tree exists for the leaves or the leaves for the tree. But in all the higher animals, the parts manifestly exist for the whole, not the whole for the parts.

Purpose is more traceable, and cause less so, as we ascend in nature.

This truth, that purpose is most clearly discoverable where cause is least so, has not received the attention it deserves.

But all the purposes that biological science reveals to us are only relative purposes—that is to say, purposes which are means to other purposes: we learn nothing of any absolute, ultimate purpose, which is an end in itself, and not a means to some other end. Thus, the purpose of the eye is to see, of the ear to hear, of the lungs to aërate the blood, of the heart to circulate it, &c.: every organ ministers to the life of the whole organism. As Kant acutely remarked, in an organism all the parts are mutually means and ends: meaning, that all the parts mutually minister to each other. But if we ask what *absolute* end is served by this wondrous play of means and *relative*

Purposes in organization are only relative.

ends, physical science gives no hint or suggestion of any answer. If any question concerning any absolute purpose in creation is capable of being answered at all, it is not by science that it can be answered.

Nevertheless, I believe that science does place on a secure basis the theory of relative means and purposes in the organic creation, as distinct from mere physical cause and effect; and I think this truth has been obscured to men's minds in this country by the use of the awkward and inaccurate expression *final cause* in the sense of creative purpose. This expression is doubly wrong: creative purposes, as made known in organic adaptations, are not causes, but, as I maintain, belong to another class of relations; and they are not final, for they are not ends in themselves, but only ends which are also means.

Final cause, an inaccurate expression.

From my saying that I do not regard the relation of means and purpose in organization as being a case of the relation of cause and effect, it may perhaps be inferred that I deny the universality of the law of causation. Nothing can be farther from my thought. I have no doubt that the law of causation is co-extensive with the universe, but it does not follow that every relation in the universe must be a case of causation. The analogy of human art may make this clear. Every machine and every engineering work has been constructed by definite means, and for a definite purpose; but the question, by what *means* it has been constructed, is distinct from the question, for what *purpose* it has been constructed; and a statement that answers the one is no answer to the other. The purpose of the Menai tubular bridge was to shorten the distance between the capitals of England and Ireland: but this statement gives no information as to the way in which that wonderful structure was put together and raised into its place. I shall have to give reasons farther on for believing that the same perfect distinctness of purpose from cause, or origin, holds good in biology; and that the adaptations of organization, like those of human art, are to be referred to the operation of an intelligence that transcends ordinary phy-

Organic adaptation implies intelligence.

sical causation, though working in connexion with ordinary physical causation, and through it.

Purpose not discoverable in the inorganic creation.

It is certainly a most remarkable result of the scientific study of nature, that so long as we confine ourselves to the study of the inorganic world, science has nothing whatever to tell of creative purpose. We may no doubt believe that the laws of gravitation and heat, and the chemical properties of substances, have been created with the special purpose of giving origin and constitution to this universe of ours, and of ministering to the life that it sustains. We may believe that the sun has been created for the purpose of giving light and heat to the planets; that the planets have been created for the purpose of supporting life on their surfaces; and that coal, iron, and other minerals have been stored for the service of man. All this may be true: science does not contradict it: but it forms no part of science. The purpose of any physical or chemical law is a question on which science has no light to throw—a question with which science has nothing to do. Nor does science answer any question as to the purpose of any cosmical arrangement: such as, for instance, the forms of the planetary orbits, or the distribution of minerals in the crust of the earth. All the questions that science can answer about these concern not purpose, but cause, law, and origin: it can explain the dynamical laws of the planetary motions, but not the purpose for which they have been set in motion: it can explain the origin of geological strata, but not the purpose of their formation. We may believe that every planet and every rock-stratum has its divinely-appointed purpose, but no such opinion ought to, or can, modify our conclusions as to the laws of their formation.

But in biological science it is totally different. There half the questions that arise concern the purpose, or special function, of organic structures in relation one to another; and every physiologist is aware that the most important question concerning any organ is, what is its function, or purpose, in relation to the whole organism. What, for instance, would our knowledge of the eye be

worth, if we did not know that it was the organ of sight?

But this is to be understood with a very important limitation. All that we can assert with any certainty concerning purpose in organization, relates only to the purpose of one part of an organism in relation to the other parts, and to the whole organism. Concerning the purpose of any organism in relation to the other organisms around it, and to the universe at large, science gives no more information than it does about purposes in the inorganic creation.

CHAPTER XI.

ORGANIC DEVELOPMENT.

IT has been stated in the last chapter that life exists prior to organization, and is the cause of organization. The germs out of which all organisms are developed are without organization or structure; and the process of organic development consists in the transformation of structureless "germinal matter" into the characteristic structure of the species to which it belongs. This process is essentially the same, whether the germ is nourished within the egg or within the body of the mother until its development is far advanced, as occurs among the higher animals, or whether it is cast loose while it is yet almost without structure or organization, as occurs among the lower ones.

Development consists in the acquisition of structure by a structureless germ.

Structure is defined as the constitution of the separate tissues of an organism (as, for instance, bone, muscle, nerve, leaves, or wood); organization is the relation of these to each other. The science of structure is called Histology; that of organization, in this more limited sense, is called Anatomy.

Histology is the science of tissues; anatomy, of organs.

Normally, development is from the germ, or embryo, to the perfect form. But the process is essentially the same when a lost part is re-formed. All animals possess something of this power: the newt will reproduce a lost leg, or even a lost eye; and there have been remarkable instances of similar powers in man, though in most cases it does not go farther than the healing of wounds.[1] When development goes on normally, from the germ to the mature form, it is effected by the gradual transformation of the formless

Repair of injuries a case of development

[1] Carpenter's Human Physiology, p. 355.

germinal matter into the formed material of the tissues. When it goes on abnormally in the reproduction of a lost part, it is effected in what is essentially the same way; namely, by the transformation of the germinal matter, or unformed material, which is found in small quantities throughout every living part of every organism, into the formed material of the part that is being reproduced. The food which is assimilated by an organism, whether by a vegetable or by an animal, is *vitalized* before it is *organized;* in other words, it is transformed into formless and structureless germinal matter first, and into the formed material of the tissues afterwards. This is equally true of the development of the original germ into the form of its species; of the growth of the individual to maturity, after it has assumed its form; of the renewal of tissue which is constantly going on to supply waste, even after growth has ceased; and of abnormal acts of development in the healing of wounds and the reproduction of lost parts. In all cases the assimilated food is transformed into germinal matter, and the germinal matter into formed material. It is to be observed, also, that in acquiring structure the germinal matter loses its plastic properties. The power of growth, development, and transformation generally, which is characteristic of organisms, appears to reside, not in the formed material, but in the germinal matter; and the more completely has the formed material assumed a character unlike that of germinal matter, the more completely has it lost the power of undergoing spontaneous transformation and development. This would be difficult to prove by any observations or experiments on the higher organisms, but it is at least consistent with what we know of them; and the lower ones afford experimental illustration of it. The Rhizopods are the simplest of all animals, and scarcely present a trace of organization; but many of them show, in its simplest form, the distinction between germinal matter and formed material. The *gromia,* for instance, consists of nothing but a minute mass of gelatinous matter, enclosed in a membranous sac, which is open at one end.[1] If the

Germinal matter is without structure.

Formed material cannot be further transformed.

Gromia.

[1] Carpenter on the Foraminifera, published by the Ray Society, p. 63.

gelatinous matter is emptied out of the sac, it will form a new sac for itself; but the sac will not form any germinal matter, nor will it manifest any vital properties. Here is the first and simplest distinction of germinal matter and formed material; and we see that the germinal matter will produce formed material, but the formed material will not produce germinal matter.

Formed material, however, is also produced in another way; not by separation from the germinal matter, as I have just described in *gromia,* but by gradual transformation of the germinal matter itself into formed material. It is in this manner that a fibrous structure, a kind of rudimentary muscular tissue, has been observed to originate in the larvæ (or, to speak more correctly, the free swimming embryos) of the Echinoderms;[1] and I think it likely, though I have not met with the remark, and do not speak with any confidence, that this mode of development is characteristic of muscular and other characteristically animal tissues; while development by means of the separation of the formed material from the germinal matter, as in the *gromia,* is characteristic of vegetables, and of those animal tissues in which vegetative or nutritive functions are carried on.

Larvæ of Echinoderms.

When the formed material is separated from the germinal matter, the separation takes place on the outside of the mass of germinal matter; and this gives origin to cells, of which the inside consists of the soft, half-liquid germinal matter, and the outside of harder formed material. The *gromia,* described above, is an animal consisting of a single cell; and there are whole tribes of vegetables that consist of the same, especially the Diatomaceæ and the Desmideæ, which are classed as very simple forms of Algæ. A great part of the tissues of the higher animals and vegetables consists of such cells, variously modified. So common, indeed, is this simple formation, that the cell used to be regarded as the primary element of all organized tissue whatever; but the observations on the larvæ of the

Cells.

Cellular tissue.

[1] Professor Wyville Thomson on the Embryology of the Echinodermata, *Natural History Review,* October 1864.

Echinoderms mentioned above, and many others, have shown that such is not the case.

In speaking of the *gromia*, we have seen that germinal matter will produce formed material, but formed material will not produce germinal matter. In the case of the higher organisms, it is of course impossible to give the same experimental proof; but all evidence and all analogy leads to the conclusion that the same relations hold throughout the whole organic creation. Germinal matter, similar in

Sarcode.

appearance and general properties to the *sarcode*, or gelatinous living substance of such organisms as *amœba, gromia,* and *hydra,* is found in the tissues of all living organisms, and is most abundant in those which are growing most

White blood-corpuscles.

rapidly. It is also found in the blood: the "white blood-corpuscles" consist of this germinal matter, and are without structure, but show their vitality by spontaneous movements like those of an *amœba.*

But it may be objected to this theory, that if the formative powers of an organism reside in the as yet unorganized germinal matter dispersed through it, a cut-off part of one of the higher organisms ought to manifest independent vitality, like a cut-off part of a *hydra,* which, in virtue of its germinal power, will transform itself into a complete *hydra.*

Why the higher organisms do not live when cut in pieces.

I reply, that the difference in this respect between the lowly *hydra* and the highest organisms, such as an elephant or a man, consists in this: that any fragment of a *hydra's* body can live wherever it has water and food; but the germinal matter of the higher organisms has no such power—it can only live within the body of an individual of the species to which it belongs, and when this is greatly injured its germinal matter dies with it.

The same difference explains the difference between the mode of propagation among the lowest organisms and the highest ones. It is probable, though not yet certain, that true sexual generation is universal among all organic

Propagation by spontaneous division,

species. But the lowest organisms, such as the Rhizopods among animals and the Di~~p~~tomaceæ among plants, often a
propagate by spontaneous division: the organism separates

into two parts, each of which contains a portion of germinal matter, and continues to live and to grow. The *hydra* is a little more highly organized than these, and, so far as is known, does not spontaneously divide, though, as already mentioned, separated parts will live. Its usual mode of propagation is by means of buds, which may be formed on any part of its external surface, and rapidly develop into perfect *hydræ*, when they detach themselves and creep away. This mode of propagation is, as every one knows, very common among plants, except that the buds of plants seldom detach themselves.

and by budding.

In these modes of propagation the reproductive power belongs to every part of the organism alike; but in the higher animals the reproductive power is confined to the organs of generation, the function of which is to prepare and throw off masses of germinal matter in such a form as shall be best suited for independent life, and, further, to provide the germ with protection and nourishment, either in the egg or in the womb of the mother, until it has attained to some degree of maturity.[1]

Separate generative organs in the higher classes.

We have seen that all living beings whatever have been developed out of perfectly simple germs, and that the germs—the germinal matter—of all species and all classes are to appearance exactly alike. This is no mere inference, but an observed fact. The further question is now suggested, whether this course of development, which is repeated in the biography of every individual organism, has taken place in the history of every species. Have species and classes of organisms, like individuals, been

Origin of species: is it also by development from simple germs,

[1] It will be observed that I have adopted Dr. Beale's views on the subject of "germinal matter," as set forth in his edition of Todd and Bowman's Physiology. I regret, however, that Dr. Beale has stated a theory, which I believe to be true and most valuable, in language that can scarcely fail to excite a prejudice against it. He speaks of life as being confined to the germinal matter; by life, evidently meaning the formative principle. In the sense in which he uses the word, I have shown that I think he has given reasonably good proof that it is so. But it is an unwarrantable liberty with language, to use the word *life* in a sense which would exclude the contractility of muscle, and the sensibility of nerve, from the denomination of vital functions.

produced by slow and gradual development from perfectly simple germs? or is the presumption in favour of the old belief, that every species has been separately created, and created as we find it? According to the "theory of development," as it is usually called, all the organic species, vegetable and animal, which are living or ever have lived, are descended from one or a few ancestors, which had life, but not organization; and all the wondrous organization and other vital properties which the various species of organisms possess, over and above those powers of transforming matter and energy which, as we have seen, constitute the differentia of life, have been acquired by gradual modification through descent for countless generations. I have purposely stated the development theory in its most extreme form. Various intermediate theories — compromises as they may be called—are no doubt possible between the development theory and the opposite theory of separate creations. We may suppose separate ancestors, for instance, for the animal and vegetable kingdoms, or separate ancestors for each of the great primary divisions of the two kingdoms, or for groups of any less magnitude. But these compromises are seldom made, and are scarcely worth any attention. It appears to be generally felt that the same arguments which are relied on to show the strong probability of the common origin of distinct though nearly allied species—as, for instance, the horse and the ass—are equally valid for showing the probability of a common origin for all organic species whatever.

through descent with modification?

I believe so.

I am a believer in the development theory to its fullest extent; and I intend in the succeeding chapters to state my reasons for thinking that there is an accumulation of probabilities in its favour almost amounting to proof. I believe that the arguments in its favour will appear stronger the more the subject is understood; and that the objections to it, on the contrary, are more apparent than real.

Deviations from strict logical method.

I must apologize beforehand for the deviations from strict logical method which the reader may expect. In writing on any subject to which demonstration is applicable, nothing ought to be taken as proved until it is

proved. But these are inquiries in which demonstration is out of the question. The proof is, perhaps, equivalent to demonstration, but it is not of the same kind: it consists of an accumulation of probabilities; it rests on the consistency of the argument with itself, and with a multitude of facts of various sorts; and it involves laws with which at first sight it may appear to have nothing to do. In elaborately stating an argument of this kind, I fear it will be scarcely possible for me to avoid appearing sometimes to take that for granted which I mean to prove.

Origin of species, and origin of life, distinct questions.

It is to be observed that the origin of species and the origin of life are totally distinct questions. As stated above, I believe that species have originated by descent, with modification, from one originally vitalized but unorganized germ, like the germs of existing organisms. But, as stated in the chapter on the Chemistry of Life, I believe that the original germ must have been vitalized by the same Creative Power that gave their origin and their properties to matter and energy.

On these two points I agree with the views stated by Darwin in his work on the "Origin of Species." But to Darwin's special and characteristic theory I am altogether opposed. I do not believe that "natural selection among spontaneous variations," or any other physical process or agency whatever, will account for the most remarkable facts of organization.

CHAPTER XII.

THE DIRECTION OF DEVELOPMENT.

Highest development is greatest complexity,

AS we have already seen, all development is from the simple to the complex: all organisms have their origin in perfectly simple germs, and their development goes on to constantly increasing complexity. Consequently, the highest development is the greatest complexity; the highest organisms are those of most complex structure.

and greatest distinctness of dissimilar parts.

But when we say that the most complex organisms are the most highly organized, we do not mean that high organization consists in mere multitude of parts. The multitude of leaves on a tree is no mark of high organization. What constitutes high organization is not *multitude* of *similar* parts, but, what is quite different, *distinctness* of *dissimilar* parts. In man, or any other of the highest organisms, there are no two parts exactly alike, except those which correspond with each other on the opposite sides of the body.

In the chapter on the Dynamics of Life it has been stated that all organisms are constantly acquiring matter by assimilation, and parting with it by waste; and that they are also constantly storing energy, and parting with it again—transforming it, usually, into either motion or heat: and, moreover, all organisms propagate their kind, whether by spontaneous division into parts, or in some other less simple manner. All organisms whatever, consequently, even those which are so simple as to be without structure, have a considerable complication of functions: and progressive organic development consists in the fitting of

separate parts of the organisms for the discharge of the separate functions; one set of organs for the nutritive or assimilative function, another for the excretory, another for the motor, another for the reproductive, and so on. To use an expressive metaphor—and, indeed, more than a metaphor, a real analogy—vital organization consists in framing the various parts of the organism for the *physiological division of labour;* and those are the most highly organized beings in which the distinctness of tissues and organs, and consequently the physiological division of labour between them, are carried the farthest.

Physiological division of labour.

In the lowest organisms, as we have seen, every part discharges all functions: there is no physiological division of labour at all. And even in the highest it is not complete: some of the organs have to a great extent the power of discharging the functions of others. In man, for instance, the skin and the kidneys are to a great extent able each to do the work of the other in separating water and soluble substances from the blood; and in some cases of disease one excretory organ assumes the whole work of another. This power, which is so utterly unlike anything in human machinery, is no doubt in some way due to the common origin of all organs and all tissues in the body in the original homogeneous and structureless germ.[1]

Never quite complete.

But, as we have seen, the highest organization is that in which the various parts are each most thoroughly fitted for its own peculiar function, and where, consequently, each part has least power to discharge any function, or do any work, other than its own. It follows from this that the highest organisms are those in which the combination of the action of the various parts is most perfect; and in them, also, the combination of the action of the various parts is most necessary. In other words: in the highest organization the various parts minister to each other most perfectly, and are least able to do without each other. In such a low organism as a *hydra*, for instance, the mutual dependence of parts is so slight, that if the animal be cut in pieces, each part will become a perfect individual; and

Combined action of parts is most perfect in the highest organisms.

[1] Carpenter's Human Physiology, p. 374.

the same power belongs to many worms, which are much more highly organized than the *hydra;* but in no vertebrate animal does this power extend further than to the reproduction of lost parts; and in man, and other warm-blooded animals, it usually extends, in mature life at least, only to the healing of wounds. Thus, the higher the organism, the less are the parts able to do without each other.

Physiological centralization, or combination.

I have used an analogy drawn from the science of man's social relations to illustrate the unlikeness of structure and separation of function between the various parts of the organism; and I may use another analogy from the same science to illustrate the mutual dependence of parts, and the combination of their actions, which is the result of that unlikeness. The separation of their functions is called the *physiological division of labour:* their mutual dependence, and the combination of their action, may be called *physiological centralization.* In the organism, as in human society, division of labour is necessary to combination; and combination (or centralization, as it is called in politics[1]) is necessary to division of labour. It appears to be a general law, grounded in the nature of things, that

Special perfection in an organ is incompatible with general adaptability.

high perfection for any special purpose is in a great degree incompatible with adaptation, or adaptability, to a variety of purposes. This is true alike of tools, of members of the living organism, and of men. It is impossible, for instance, for a hammer and a plane to do each other's work. It is inconceivable that the hand and the eye should exchange functions. And it is a familiar remark, that a man who has attained to perfection in some mechanical—and perhaps I may add, in some intellectual—employment is thereby in a great degree incapacitated from any employment that needs nothing but the power of doing a variety of work

[1] I ought perhaps to remark here that any argument in favour of political centralization which may be based on this analogy is not only too *far-fetched* (to use a most appropriate colloquial metaphor) to be of much practical value, but it is utterly vitiated by this difference, which is practically all-important, that in the living organism the parts exist for the whole, but in society the whole exists for the parts—society exists for its members.

moderately well. In the living organism, and in human society alike, the purpose of division of labour is to increase the efficiency of every member; the purpose of combination, or centralization, is to increase the efficiency of their combined action: each of these—division of function and combination of action—is necessary to the other, and is involved in the other.

Efficiency of each and all members increased by division of labour and combination.

From physiological division of labour follows definiteness of the number, position, and form of parts. Where every part has its perfectly definite function, it follows that the number, form, and position of the parts must be definite. We find that in the lower organisms the number of the parts, especially, is often very indefinite; but as we ascend in the scale of organization this characteristic disappears. Nothing, for instance, can well be less definite than the number of leaves on a bough; but in the flower, which is by far the most highly organized part of the plant, the number of the petals and of all the other parts, in many important classes at least, is perfectly definite. And in worms and millepedes the number of segments is indefinite, being variable between different individuals of the same species; but among insects, crabs, and spiders, which are more highly organized on the same fundamental plan, the number of segments is constant.

Definiteness, a result of division of labour.

Leaves and flowers.

Worms, millepedes, and insects.

What precedes may be summed up by saying, that the higher the organization the more complete are the *physiological division of labour*, the *physiological centralization*, and the *morphological definiteness*.

Summary.

It would be impossible to give a full account of all the tissues and organs which become distinct from each other in the development of all the various classes of organisms, without writing a complete treatise on comparative histology and anatomy. But this is the place to describe in outline the chief distinctions of the functions, and of the corresponding organs, which we find in all organic forms, except the very lowest.

The first and the only universal distinction of organs is that produced by the gelatinous matter which constitutes

Separation of internal

and external parts, universal. the whole substance of some of the lowest organisms becoming more consolidated on the outside than in the inside. Thus are produced the single cells of which consist the Diatomaceæ among plants, and the Gromia among animals; and there is probably no organism, not even the Amœba, which does not present this character in some degree. The higher organisms, as already stated, consist (at least in great part) of masses of variously-modified cells; and in them the external cells are usually condensed into a comparatively denser and sometimes hard tissue, the function of which is to protect the interior organs; while the tissues of the interior, where the vital processes go on, continue soft. So that in the highest organisms and in the lowest alike the exterior parts are consolidated, in order to protect the interior parts and hold them together.

External parts protective.

Separation of nutritive and reproductive organs, not universal, The next distinction that we meet in the ascending scale of nature is that into the nutritive and reproductive organs: in other words, into the organs which minister to the life of the organism itself, and those which provide for the existence of future organisms of the same kind. This distinction is not absolutely universal among organisms: among the Diatomaceæ and Desmideæ, which are very simple forms of Algæ, the whole organism is capable of acting as a reproductive organ, in a way to be hereafter described; besides that many, probably all, of the lowest vegetables and animals alike propagate their race by spontaneous division into parts, a characteristic from which the Diatomaceæ have their name.

and not fundamental. It is important to observe that the distinction between the nutritive and the reproductive functions is not fundamental. The reproductive function is only a particular form of the nutritive. Reproduction essentially consists, as already stated, in separating from the organism a small portion of formative material, or germinal matter, under such circumstances as to enable it to build up a completely new organism. But the properties of the germinal matter which is thus detached for the formation of a new organism do not essentially differ from the properties of the germinal

matter which is retained in the old organism, and ministers to the growth or renewal of its tissues.

Separation of cellular and vascular structures.

The next distinction is that into cellular structure, which is generally in animals, and probably always in vegetables, that in which the nutritive processes are actively going on; and vascular structure, which, in its simplest form, consists of rows of cells which have been joined to each other by the removal of part of their walls (as rooms may be thrown together by the removal of partitions), so as to form tubes for the conveyance of nutritive fluids from one part of the organism to another.[1] Vessels are not needed, and consequently they do not exist, in those organisms where all the parts are alike in structure, and equally well situated for obtaining nourishment. For this reason they are not found among the Algæ, every part of which is able to derive its nourishment separately from the water; but some rudiment of vascular structure is found in all air-breathing plants, except the simpler lichens and fungi,[2] in which any movement of fluid that may be necessary takes place by permeation. For all tissues in which vital processes are going on are permeable by water.

Cells unite to form vessels.

The reproductive organs, and the vascular or circulatory organs, which are thus separated from the general nutritive system, continue, notwithstanding, to form part of the organs of *nutritive or vegetable life.* But in the animal kingdom, and in a few instances in the vegetable kingdom also, a still more profound distinction is established. We have seen that all organisms transform matter and energy; that the differentia of life consists in the power of effecting a peculiar set of transformations of matter and energy. The peculiar characteristic of animals, though some vegetables share it to a slight extent,[3] is the possession of a

Separation, in animals,

[1] The canals by which the substance of Sponges is traversed can hardly be called structure at all; and what they circulate is not sap or blood, but only the water from which the sponge derives its nourishment.

[2] Carpenter's Comparative Physiology, p. 671.

[3] Cohn has found the structure of the filaments of the stamens of the thistle to be closely analogous to that of involuntary muscle. For about twenty-four hours the anthers, if touched, show a peculiar twisting motion, and extrude pollen. (Medico-Chirurgical Review, January 1864.)

of nutritive and nervo-muscular systems.

distinct apparatus for the transformation of energy. This is the nervo-muscular system, which constitutes the organs of *animal life,* though none of these organs are to be distinguished in the very lowest animals.

A muscular system is found in some animals—among the *hydrozoa,* for instance—which have no rudiment of nerves; but the converse is not the case: there are never any nerves except where there are distinct muscles. Nerves are to the muscular system what sap- or blood-vessels are to the nutritive system. The analogy is not close, but it is real. The function of the vascular or circulatory system is to increase the efficiency of the nutritive system by conveying nutritive material from one part to another; and *the primary function of the nerves is to increase the rapidity and precision of combined action among the muscles,* and thereby to increase the efficiency of the muscular system by *transmitting stimuli from one part to another.* It was said long ago by John Hunter, that the primary function of the nerves was *internuncial;* and Helmholtz has shown by a most ingenious experiment that some influence—in some respects like electricity, but not identical with it—runs along a stimulated nerve with a great but measurable velocity. On stimulating by electricity a piece of muscle taken from a newly-killed frog, the muscle contracted. On applying the electric stimulus, not to the muscle itself, but to the loose end of a nerve in connexion with the muscle, the muscle again contracted; but between the application of the stimulus to the one end of the nerve and the contraction of the muscle at the other end a time elapsed which, though quite too short to be perceptible to the eye, was measured by the delicate apparatus employed by Helmholtz, and enabled him to estimate the rapidity of the transmission of impulses along the motor nerves of the frog at from 81 to 126 feet per second.[1]

Nerves are to muscles what vessels are to nutritive system.

Internuncial function of nerves.

Helmholtz's experiment.

Velocity of nervous stimulus measured.

Nerves, probably, transmit energy.

But what is it that is transmitted along the nervous fibres? I think it is scarcely possible to doubt that it is

[1] Carpenter's Human Physiology, pp. 473, 474. It would be nearly impossible to explain the apparatus by which the time is measured, without a diagram. Of course it is electrical.

some form of vital energy. If so, there is this remarkable parallelism: that the function of the nutritive system is to transform matter, and of the muscular system to transform energy; the function of the vessels is to convey matter, and that of the nerves to transmit energy.

Each muscle usually transforms energy for itself.

I must, however, state, in order to avoid a possible misconception, that the energy put forth by any muscle is not brought to it by its nerves, but transformed into motor energy by the muscle itself. There may possibly be exceptions to this in the constantly-working muscles of the heart and lungs; but it is certainly true of the voluntary muscles, as is shown by the familiar fact, that fatigue is felt most in those muscles that have been most overworked. The relation of the nerves to the muscles may be compared with the relation of the mind of the master who gives orders, to the muscular force of the workmen who execute the orders.

It ought also to be observed, that in the well-known experiment of making the cut-off legs of a frog kick by means of an electric stimulus, the electricity is a *mere* stimulus, an excitor to action, but does not supply the motive power; the motive power is obtained by the transformation of vital energy, as in the living frog. The proof of this is, that the cut-off legs *become fatigued* with repeated stimulation, and respond less forcibly, but recover their power when laid by for a time, which would not be the case if the motive power were supplied by the transformation of the electricity. Of course the same applies to the muscle and nerve in Helmholtz's experiment.

Hydrozoa and bryozoa.

Where there are no nerves, as in the *hydrozoa*, the muscular tissue has itself the power of transmitting stimuli: thus, if one of the tentacles of a *hydrozoon* be irritated, not only that tentacle but the others will contract. In this class, however, the propagation of the stimulus is relatively slow, and, consequently, if one tentacle is irritated the rest will contract but slowly. The *bryozoa* are a molluscan or molluscoidan class, adapted to the same kind of life as the *hydrozoa*, but with a totally different anatomy, and a discernible, though rudimentary, nervous system;

and among them, if one tentacle is irritated, the rest will contract instantaneously.[1]

As already stated, the parts of organisms in which nutritive processes go on (as, for instance, young buds, animal and vegetable embryos, and secreting organs) mostly consist of cellular tissue; and vascular structures, among vegetables certainly,[2] and probably among animals also, consist of modified cells. This is shown both by the history of their development among the higher vegetables, and by the fact that among the higher fungi and lichens we meet with cells elongated in the direction of the length of the stem, which are evidently a transition from simply cellular to vascular structure.[3] Cellular and vascular structures are thus probably akin; and the parallel relation between muscle and nerve is, I think, shown (though I do not wish to lay any stress on this) by the resemblance of the minute structure of nervous fibre to that of muscular fibre.[4]

Development of vessels out of cells.

Resemblance of nervous fibre to muscular.

But the parallelism of the circulatory and nervous systems is far more unmistakeably shown in various other ways. The nerves and the blood-vessels resemble each other in ramifying and inosculating[5] throughout the entire body; and also in this, that the action of both is in a great degree (though, as careful researches have shown, not absolutely) controlled by great central organs; the circulatory system by the heart, and the nervous system by the brain. Circulatory centralization and nervous centralization, as they may be called, are seen to increase together as we ascend in the animal scale: that is to say, the higher is the organization of any animal, the more complete is the centralization both of its circulatory system, and consequently of its nutritive or vegetative life,—and of its nervous system, and consequently of its animal life. It is

Blood-vessels and nerves ramify.

The heart and the brain.

[1] Spencer's Principles of Biology, vol. ii. p. 368. [2] Ibid. p. 264.

[3] Carpenter's Comparative Physiology, p. 671.

[4] For the fact of this resemblance, see Beale's edition of Todd and Bowman's Physiology, p. 72.

[5] To inosculate means to reunite after ramifying. But though nerve *trunks* ramify and inosculate, it is believed that the ultimate nerve-*fibres* remain always distinct.

a most interesting instance of this, that the *amphioxus*, a species of fish which is the lowest of all vertebrates, is at once without a brain, though it has a spinal cord, and without a distinct heart, instead of which it has several pulsating enlargements of the blood-vessels.[1] These two characters make it quite unique among vertebrates, and probably show that it is a link between the vertebrates and some now lost class of low organization.

Amphioxus.

The parallelism between the circulatory and nervous systems is further shown in this, that those parts of the body which are the most abundantly supplied with blood-vessels are also the most abundantly supplied with nerves; and the nails and hair, which have no supply of blood at all, are also without nerves.[2] The activity of the two is heightened or lowered together. The vessels of inflamed parts are unusually full of blood, and the action of their nerves is heightened: this last is proved by increased sensibility, and also, as I have shown reason for believing, by elevated temperature.[3] And, what is a parallel fact to this, the blood-vessels of the brain are comparatively empty during sleep, which essentially consists in a lowered action of the brain; and the same is true of the blood-vessels of the retina.[4] It is possible to lower the nervous activity so as to destroy the sensibility of any part, by tying the arteries so as to deprive it of its supply of fresh blood.[5] It belongs to this class of facts that the heart, which is the central circulatory organ, is more easily acted on by nervous influence than any of the other organs of the vegetative life.[6] The susceptibility of the heart to influences arising from the emotions has caused it, indeed, in popular language, to be regarded as their seat.

Blood-vessels and nerves are abundant in the same places.

Their action is heightened together.

Inflammation.

Sleep.

Want of fresh blood causes insensibility.

Connexion of heart with brain.

We have seen how dependent is the activity of the nervous system on the supply of blood. But the converse is not true: the activity of the circulating system does not

Dependence of nervous action on

1 Carpenter's Comparative Physiology, p. 447.

2 Carpenter's Human Physiology, p. 604.

3 Ibid. p. 99.

4 Ibid. p. 590.

5 Carpenter's Comparative Physiology, p. 175.

6 Claude Bernard, in *Revue des Deux Mondes*, 1st March, 1865.

circulation not reciprocal.

in any similar way depend on nervous agency. Thus, as just stated, the nerves of a part are paralysed by tying the artery that supplies it; but the circulation of a part is not paralysed by cutting the nerve-trunk that supplies it.

Opposite relations of blood and nerve to muscle.

Recent experiments on cold-blooded animals have shown a very remarkable contrast between the relations of blood and nerve to muscular fibre. We know that the stimulation of a nerve tends to cause the muscle in connexion with it to contract. It is now ascertained that the supply of fresh arterial blood tends to cause the muscles that it bathes to retain the elongated state; and when the supply of blood is cut off, the muscles tend to contract spontaneously.[1] In other words, blood tends to keep the muscles elongated and relaxed, and nervous action makes them contract. To state these facts in the language of the dynamic theory:—The blood undergoes oxidation in the lungs: in the process of oxidation energy is liberated, part of which is carried by the blood to the muscles, and supplies them with their charge of static vital energy.[2] So long as they remain elongated, the muscles retain this charge of static vital energy; but when a nervous stimulus comes and makes them contract, this vital energy is transformed into motor energy.

It is to be observed, that the elongated or relaxed state of a muscle is that in which it contains a charge of energy, and the contracted state is that in which the energy has been parted with. This distinction is one on which emphasis must be laid, for it is very important, and by no means obvious. It is totally unlike that which obtains in an elastic body, such as an india-rubber cord; for the india-rubber contains a charge of energy while it is strained, but none while it is relaxed.

It is also proved by the foregoing facts that the blood

[1] See Dr. Norris's Report on Muscular Irritability, British Association Report, Nottingham, 1866. This law, I believe, was first stated by Dr. Radcliffe. (Carpenter's Human Physiology, p. 680.)

[2] See p. 97. The theory that the motor energy produced by any muscle is due to the oxidation of that muscle at the very moment, is, I think, conclusively disproved by the experiments of Fick and Wislicenus. (See Philosophical Magazine, June 1866.)

supplies the various parts of the body with energy as well as with matter. The nerves, of course, transmit energy only.

Blood supplies energy as well as matter.

What has been said on the direction of animal development may be thus summed up :—

Summary.

Every organism transforms both matter and energy, and it is probable that every living part of an organism always continues to transform them both. But the characteristic of animal development is, that one set of organs—the nutritive—is specially appropriated for the transformation of matter; and another—the nervo-muscular—for the transformation of energy. The nutritive, or vegetative, system of organs is for the most part internal, and the characteristically animal organs—those of the limbs and mouth, with their muscles—are external to the nutritive. In both vegetables and animals, a vascular, or circulatory, system is developed, the function of which is to minister to the nutritive life by the circulation of nutritive fluid; and in animals a nervous system is developed, the primary function of which is to ensure the harmonious and efficient action of the muscular system, by the transmission of stimuli from one part to another.

Ganglia.

The foregoing account of the relation of nerve to muscle, however, would be most imperfect were it not mentioned that nerve-fibres never exist without ganglia, which are situated at the junctions of the fibres, and from which the fibres radiate throughout the body. The action of ganglionic tissue is even more mysterious than that of nerve-fibre. It appears, however, to be a universal law that one fibre can communicate a stimulus to another only through a ganglion. In the higher animals, sensation and thought are produced in some altogether inscrutable way by the mutual action of the ganglia and the nerve-fibres: sensation can be produced neither in a ganglion unless it is acted on by a nerve-fibre, nor in a nerve-fibre unless it is in communication with its ganglion.

Sensation.

NOTE.

THE FUNCTIONS OF THE NERVOUS SYSTEM.

Lewes's theory of sensation

MR. LEWES, in an admirable treatise on nervous action, which forms part of the second volume of his "Physiology," has advanced the opinion that all mutual action of ganglia and nerve-fibres is accompanied by sensation. He thinks the action of the visceral nerves, of which we are unconscious, goes to make up the sense of being alive. This theory is plausible, and it might appear impossible to prove it wrong; but I think it is disproved by the fact, that cases of blindness have been observed in which, though there is total insensibility to light, the pupil continues to contract in light and expand in darkness.[1] There are special nerves for this expansion and contraction; and the fact just quoted, I think, proves their action to be quite independent of sensation.

disproved.

Impossible to say where sensation begins.

This instance, and many others, though I know of none so striking and conclusive, show how impossible it is to determine where sensation begins; and if a large part of man's nervous system is insentient, it does not appear anomalous or improbable that the whole nervous systems of the lower worms and mollusca should be so. I believe the most probable guess we can make is, that in the ascending scale of organization sensation begins with the first appearance of organs of special sense; and the most generally distributed organs of special sense among animals appear to be the eyes.

Nerve-fibre may act without ganglionic influence.

It has been often repeated that the ganglia are generators of nervous energy, and the nerve-fibres its conductors. I agree with Mr. Lewes, however, that this account of the matter is, at least, insufficient. A nerve-fibre is capable of acting even when it is not in communication with a ganglion; as is proved by the well-known experiment of making the cut-off leg of a frog kick by means of exciting its nerve with electricity, and also in the experiment mentioned in the foregoing chapter, by which Helmholtz has measured the velocity of the nervous current.

[1] Carpenter's Human Physiology, p. 533.

CHAPTER XIII.

ORGANIC SUBORDINATION.

Organic differentiation and integration,

WE have seen in the last chapter, that the highest organic development is the most complete physiological division of labour, and the most perfect physiological centralization. In the lowest organic species, and in the germs of the highest, the parts are all alike and all independent of each other; in the mature forms of the highest species the parts are all different, and the whole organism is bound together into one system, with all its parts mutually dependent. To speak technically, organic progress consists in increasing *differentiation* and increasing *integration*.[1]

dependence and subordination.

Besides these, there are within the organism relations of *dependence* and of *subordination*, which I have now to describe. Before stating the relation of organic dependence, I must go back to the inorganic sciences.

Space and time are conditions of all things.

Consequently mathematics is the ground of physical science.

Whatever exists, so far as is known, or can be known, to us, exists in space; and whatever acts, acts in time. Consequently the properties of space and time are conditions of all existence and of all action; the laws under which things exist and act cannot be proved, nor even stated, without express or implied reference to the properties of space and time. It results from this, that mathematics, which is the science of the laws of space and time, is the necessary ground of physical science. To take the very simplest instances: it would be impossible to prove, or even to state, the law of the parallelogram of forces, unless

[1] The word *differentiation* is now generally used in this sense. *Integration* is a parallel word to it, and is used in Spencer's Biology.

the geometrical properties of the parallelogram were known; and it would be impossible to prove, or to state, the law that the energy due to a moving body is proportional to the second power of its velocity, unless the nature of powers and roots were known. Mathematics is thus necessary as a foundation for dynamics.

Dynamics, the basis of physical science.

Among physical laws, the most general are those of force: the laws of force, or, as they are generally called, the laws of motion, are the only laws which are true of all action whatever. Consequently, dynamics is necessarily the basis of physical science: or, in other words, the theory of force is necessary as a basis for the sciences of material things.[1]

Secondary dynamical sciences.

The sciences of sound, radiance, heat, electricity, and magnetism, are merely particular cases of dynamics, being applications of the theory of force to special kinds of actions.

The laws of force apply to all the actions of all matter; but there is a great variety of laws that apply only to those actions, or functions, which are characteristic of particular kinds of matter: I mean the laws of chemistry. The laws of chemistry depend on those of heat and electricity in a very great degree; so decided indeed is the dependence, that it would be impossible so much as to state many of the most important chemical laws, unless the elementary laws of heat and electricity were taken as known.

Chemistry.

Biology.

Finally, the properties of living organisms, and their peculiar actions, in a great degree depend on the general properties of force, and on the special properties of the chemical substances of which the food of the organism, and the organism itself, are composed. Vital properties are certainly more than mere resultants from physical and

[1] It may be said that I contradict myself in calling mathematics the *ground* of physical science, and dynamics its *basis*. There is, however, no contradiction. Dynamics is a part of physical science, but mathematics is not. Physical science is built on mathematics, as a building on the ground; the other parts of physical science are based on dynamics, as the higher parts of a building on its base.

I attach no importance to these metaphors, but I wish to show that I have not fallen into any inconsistency.

chemical ones, but life does not suspend the ordinary physical and chemical properties of the substances in the organism; on the contrary, it works through them. Consequently, the action of life depends on the properties of the materials it has to work with; and it is impossible to understand the nutritive functions of organisms, without some previous knowledge of chemistry. It would have been impossible, for instance, to explain the nature of respiration, which is a slow combustion, unless the nature of combustion had first been discovered.

So that we have this series:—

Series of sciences,

1. Mathematics, or the science of the properties of space and time.

2. Dynamics, or the science of the laws of force in general.

3. The secondary dynamical sciences, being those of sound, radiance, heat, electricity, and magnetism; all of which are particular applications of dynamical theory.

4. Chemistry, or the science of the special properties of particular kinds of matter.

5. Finally, biology, or the science of the properties of living beings.

each dependent on the preceding.

In this series, each member is dependent on that which goes before it, but independent of that which comes after it. Biology is dependent on chemistry, because the actions of life on the substances in the organism cannot be understood, unless the properties of the substances themselves are known first. Chemistry is dependent on the secondary dynamical sciences, because its laws imply those of heat and electricity, and could not be understood without them. The secondary dynamical sciences are dependent on general dynamics, of which they are but particular cases. And lastly, dynamics depends on mathematics, without which it cannot make a single step in reasoning.

Dependence not reciprocal.

This dependence is not reciprocal. The truths of mathematics do not in any way depend on those of dynamics for their proof. The truths of general dynamics are true, independently of those of the secondary, or special, dynamical sciences. The laws of the secondary dynamical

sciences are true independently of those of chemistry, and can be understood without them. And the laws of chemistry are true, independently of those of life, and can be understood without them.[1] Thus the series resembles a building of several stories, each of which rests on that below it.

Dependence is not only of the sciences, but of the things.

Although, in order to avoid circumlocution, I have spoken of the sciences as depending the one on the other, yet in reality the dependence is not only of the sciences, that is to say of our knowledge of the laws, but of the laws of the things themselves. Not only our knowledge of biological laws, but the biological laws themselves, depend on chemical laws. Not only our knowledge of the chemical laws, but the chemical laws themselves, depend on the laws of heat and electricity. The laws of heat and electricity are but cases of the laws of general dynamics. And not only our knowledge of the laws of dynamics, but the laws of dynamics themselves, depend on the laws of mathematics, which are but the statement of the properties of space and time. I am not here insisting, as may perhaps be thought, on a merely identical, or self-evident, proposition. It is quite easy to conceive such a relation between two sciences, that our knowledge of the one shall be dependent on our proficiency in the other, without the subject-matters of the two having any connexion whatever.

Accidental connexion of histology with optics.

Such a relation does exist between optics, or the science of light, and histology, or the science of the minute structure of organic tissues. Histology has been created as a science by the microscope, which owes

[1] It may be objected, that this is wrong in point of fact: it may be said that chemical laws are implied in the theory of electric currents, and biological laws in organic chemistry. I reply, that electro-chemistry does no doubt imply chemical laws, and may be regarded as a branch of chemistry, but the whole theory of electro-statics and electro-dynamics may be stated without any chemical knowledge being needed. And as to organic compounds, chemistry works with them just as if they were mineral substances.

Of course the various sciences run into each other, and have many and varied mutual relations. But I think they are more distinct, and stand in simpler relations to each other, than we might have anticipated.

its existence to the advance of optics; and yet the subject-matters of optics and histology have no connexion whatever. But such a connexion is merely accidental and instrumental: the connexion of the sciences in the series which I have drawn above, on the contrary, is logical and real, and is based on the dependence of the things themselves.

Obligation to Comte.

So far, as the reader will perhaps have perceived, I have taken these ideas about the dependence of the properties of things, the one on the other, from Comte's Positive Philosophy.[1] What follows, though I claim no originality for its substance, has not, so far as I am aware, been stated in a systematic form before.

Dependence of vital laws one on the other.

We have seen that in inorganic nature, and up to the laws of life, there is a relation of dependence of the laws of one science on those of another, which dependence is not reciprocal. The same relation is continued between the different laws of life: animal or motor life depends on vegetative or nutritive life; and mental life depends on animal life. And among these also, the dependence is not reciprocal: vegetative life may exist without animal life, and animal life may exist without mental life. Mental life depends on animal life, and animal life depends on vegetative life, just as vegetative life depends on chemical properties, and chemical properties depend on those of heat and electricity. These are facts of observation. Throughout the whole vegetable kingdom we see vegetative life without animal life; and throughout a great part of the animal kingdom, we see very energetic animal life with scarcely a trace of mental life. But the converse is impossible; there is not, nor under the laws of life can there be, any such thing as animal life without vegetative or nutritive life for its basis; or mental life, without animal life as its basis. It is a consequence of this relation, that

Vegetative, animal, and mental life.

[1] See Harriet Martineau's condensed translation of Comte's Positive Philosophy, vol. i. chap. ii. I have read Comte only in the above-mentioned translation, which I believe is thoroughly trustworthy. The series I have drawn in the text differs from Comte's in detail, but is the same in principle.

the animal life may be almost, if not totally, suspended in sleep, but the vegetative life cannot be suspended for a moment without death. And another very remarkable consequence of the same relation has been experimentally ascertained; namely, that it is possible to extinguish the mental life, and in a great degree the animal life of an animal, by removing the parts of the brain that minister thereto, while the organs of the vegetative life continue to perform their functions for a considerable time. Of course in this experiment, as well as in sleep, the involuntary muscles of the heart and lungs continue to act, as on their action that of the vegetative life depends.

Sleep.

Experiment.

The series continued.

We may now thus continue the series that we saw to exist from the laws of space and time up to those of life, so as to include the three ascending degrees of life itself; each term of the series being dependent on those which go before it, but independent of those which come after it:—

1. The properties of space and time: mathematics.
2. The laws of force: dynamics.
3. Special cases of the laws of force: sound, radiance, heat, electricity, and magnetism.
4. The properties of particular kinds of matter:—chemistry.
5. The laws of vegetative life.
6. The laws of animal life.
7. The laws of mental life.

But though the dependence of animal life on vegetative life is of the same kind with the other laws of dependence that I have stated, yet it is not practically possible to treat of them apart, as the subjects of distinct sciences. The old distinction of zoology and botany must no doubt be always necessary in classificatory, or what are called systematic, works; but it would be impossible to treat the physiology of the vegetative life, and that of the animal life, as distinct sciences. With the laws of mental life it is different. They may in a great degree be adequately treated of apart; and I intend in this work to follow the usual practice, and to keep psychology, or the science of

mind, as distinct as possible from biology, or the science of life. At the same time I avow my opinion—though it is, perhaps, only a question of words—that psychology is really a branch of biology.

We have seen that the relation of *dependence* of one group of properties, or functions, on another, holds both in inorganic matter and in life. But when we come to vital functions, we find a different though parallel relation, unlike any in the inorganic world. I mean the *subordination* of one function to another: one function working through another. As I have already stated, life acts through the physical and chemical properties of matter; and it is equally true that the conscious, or vital functions, or those of the mind, act through the unconscious ones. These statements may need explanation.

Subordination of organic functions.

Life, as I have stated before, does not suspend the ordinary laws of matter and energy; life works in accordance with those laws and through them, directing their forces to the attainment of ends which they would not have attained of themselves. Thus, though life is so completely *dependent* on the ordinary properties of matter that it could not exist, nor even be conceived to exist, without them; yet life makes those properties *subordinate* to its own purposes. Exactly parallel to this is the relation of the mind to the unconscious life. The mind is *dependent* for its existence on the unconscious life: mind is a function of the nervous system; and the primary purpose of the nerves, as we have seen in the last chapter, is to enable the muscles to work together. But mind has the power of making the unconscious life *subordinate* to its purposes.

Matter subordinate to life.

This last statement will perhaps be scarcely intelligible. It may be thought that whether the mind works alone, in thought,[1] or through the body, in voluntary muscular action, all mentally directed action is conscious; and that the only unconscious life is the vegetative life, which is not under the direct control of the mind at all. This, however, would be a mistaken view. Paradoxical as it may sound, it is a

Unconscious life subordinate to mind.

[1] This expression is not strictly accurate. I shall have to show farther on, that all mental action is connected with bodily action.

Muscular action essentially unconscious.

simple truth, that muscular action is itself unconscious. We produce the motion of a particular set of muscles—those of the legs, or hands, or mouth, for instance—by a conscious mental determination; we become aware that they move as we intend, by means of the "muscular sense," which is produced in muscles by their action. But between the conscious mental determination and the sense of muscular action, there is an intermediate link of which we are utterly unconscious; namely, the special combination of muscles which is needed to effect the movement we intend. Of this we know nothing whatever except what anatomy teaches us; we effect these combinations by a perfectly unconscious instinct. Were consciousness of the required muscular combinations necessary before we could make the combinations, in the same way that, for instance, consciousness of the meaning of words is necessary in order to use the words with accuracy, we could not perform any muscular movement until we had learned the anatomy of the muscles.[1] It is indeed scarcely a metaphor to say that the brain gives its orders to the muscles without knowing the details of the way in which its orders are to be executed. An equally clear proof of the essentially unconscious nature of muscular action is afforded by the fact, that when any set of muscles, especially those used in walking, is set in motion by a determination of the will, and the attention afterwards withdrawn from their action in consequence of the mind falling into a state of abstraction or reverie, the action of the muscles often continues independently of consciousness or will. And, what is a fact of the same kind, if nervous connexion between the brain and the lower extremities is cut off by accidental injury to the spine in man, or by purposely cutting through the spinal cord in an animal, irritation applied to the feet causes no sensation, but produces convulsive movements in the legs, of which the patient is unconscious.[2]

Instance in reverie.

Summary.

To sum up what has been said:—The higher functions are *dependent* on the lower ones; the vital functions are dependent on the inorganic, and the conscious, or mental

[1] Carpenter's Human Physiology, p. 559.

[2] Ibid. p. 529.

functions, on the unconscious; but this dependence is not reciprocal. And the lower functions are *subordinate* to the higher ones, which work through them; the unconscious functions are subordinate to the conscious, and the inorganic functions to the organic; and this subordination never becomes reciprocal.

Dependence necessary: subordination not so.

It is to be observed that the dependence of functions one on the other is necessary and constant; the conscious functions are always and necessarily dependent on the unconscious ones, and life is always dependent on matter. But the subordination of functions one to the other is neither necessary nor constant; the mind often loses its control of the body, and life often loses its control of matter. When the control of the higher functions over the lower, and the subordination of the lower to the higher, are weakened, the result is disease; when they are destroyed, the result is death.

CHAPTER XIV.

ORGANIC FUNCTIONS.

Classification of organic functions.

IN the last chapter I have classed the organic functions as vegetative, or nutritive; animal, or motor; and mental. The vegetative and animal functions I have classed together as unconscious, in opposition to the mental, which are conscious. These distinctions may be most conveniently stated in the following tabular form:—

Unconscious functions .	Vegetative, or nutritive. Animal, or motor.
Conscious functions . .	Mental.

Different classifications for different purposes.

In speaking of the same subject, however, it is often necessary to adopt different classifications at different times, according as we regard it from different points of view. That adopted above shows the relations of the different vital functions as made known from the common, practical point of view of every-day and every man's consciousness, which begins with the distinction between the body and the mind. This point of view is no doubt insufficient, and its results need to be corrected by comparison with those obtained from other points of view. We are so constituted and so circumstanced, in the intellectual as well as in the physical world, that the observations taken from any single point of view are necessarily incomplete, and need to be supplemented by others. But, though incomplete, they are true so far as they go, and are untrue only when they are mistaken for the whole truth.

In the present chapter, I shall adopt a classification of organic functions which is not based, as the former one

was, on their obvious connexions. That which I am going to use is intended, on the contrary, to explain the way in which one function is developed out of another. The law of the development of organisms, as we have seen, is that they are developed out of simple germs, and that the parts are gradually differentiated the one from the other. The same is true of functions;—functions also are developed by gradual differentiation. I may not, perhaps, be able to make this last statement perfectly intelligible, until I come to the subject of mental science; it is, however, implied in the views I have to state in this chapter.

Development of functions by differentiation.

We have seen that all organisms transform matter and energy. The transformation of matter is the peculiarly nutritive, or vegetative, function; the transformation of energy is the peculiarly animal function, and is generally motor—that is to say, the energy is generally transformed into motion, though in particular cases it is transformed into heat, electricity, or light.

Their classification on this basis.

Let us speak of the vegetative functions first. The primary vegetative function, which is the ground and condition of all other vital functions whatever, is the decomposition, by plants, of water and carbonic acid, and the formation of organic compounds. This function is in its results a purely chemical one, though it produces combinations which, as I believe, no chemistry but that of the living vegetable organism can possibly produce.[1] The power of decomposing carbonic acid, and probably of decomposing water also, is peculiar to the vegetable kingdom, though not universal in it.[2] Animals cannot decompose carbonic acid, and consequently cannot form the primary, or first-formed, organic compounds for themselves; but they effect various transformations in the organic compounds which they receive in their vegetable food. Some of these transformations may perhaps be due to the ordinary chemical forces, acting as they might act in a laboratory; but some are certainly due to a peculiar vital action, controlling the chemical forces. This is eminently the case in secretion: one set of secreting cells separates

Vegetative functions chemical,

[1] P. 86. [2] See Note A at end of this chapter.

bile from the blood, another milk, and so on; for these various results are affected by glands, all of which consist of substances of the same chemical constitution; and consequently would all act alike, if their action were merely a chemical one.

and structural.

The next vegetative function consists in the arrangement of the organic compounds so as to form tissue. As already stated, the simplest tissues are cellular, and cell-formation consists in the separation, or differentiation, of the primary structureless germinal matter into consolidated substance, which forms the outside of the cell; and soft, almost fluid, substance which constitutes the cell-contents, and, at least in the simplest organisms, retains the properties of germinal matter. Many organisms, as for instance the lowest Algæ, consist of but a single cell, which propagates by spontaneous division. But in others the cells, after dividing, do not separate, but remain together; and thus cellular tissue is formed. The unicellular and multicellular forms of Algæ graduate into each other, and the Algæ in general consist of a mass of cellular tissue, with little further differentiation.

Cellular tissue.

Cells, in the various parts of various organisms, undergo endless modifications, both in form, and by acquiring the power, as stated above, of separating different substances from the sap or blood. Accordingly, the next differentiation consists in the acquisition of different characters by different masses of cells, so as to form different tissues: as, for instance, soft leafy substance and hard woody fibre, in plants; and muscle, nerve, and bone, in animals.

Differentiation of tissues.

The formation of tissues constitutes growth, and the differentiation of tissues the one from the other constitutes development. It is important to observe that growth and development are not the same thing; they do not imply each other, and do not necessarily go on together—indeed, there is frequently an antagonism between them; rapid growth and rapid development appear, at least in certain cases, to be incompatible. Thus, flowers are more highly developed than leaf-bearing branches; and flower-bearing branches are always found to have lost something of the

Growth and development antagonistic.

Leaves and flowers.

indefinite power of growth that belongs to leaf-bearing ones, and if they are supplied with abundant nourishment, so as to cause them to grow rapidly, they cease to bear flowers, and are changed back into leaf-bearing branches. A still more remarkable instance of the same kind is that of the worm-like larvæ of some insects, which at first feed voraciously and grow rapidly, forming comparatively simple and undifferentiated structures: but growth ceases when further development begins; growth ceases when the larva enters into the chrysalis state, and all the vital energies are employed in the work of development, which consists in transforming the comparatively undifferentiated tissues of the larva into the highly differentiated tissues of the perfect insect. And not only so, but the insect becomes inactive: motion ceases as well as growth, in order apparently that no energy may be spared from the work of development. As already remarked,[1] it is nearly impossible to doubt that some transformation of energy takes place in the act of development. If it is true that a charge of energy is taken up and becomes static in the act of unorganized material acquiring organization, it appears probable that a further charge is taken up in the act of development, which is the acquisition of higher organization.[2]

Insect metamorphosis.

Transformation of energy in development.

The tissues which are differentiated from each other combine into organs. In some cases at least, there is no distinction between tissue-formation and organ-formation. The shell of a mollusc, for instance, is at once a peculiar tissue and a peculiar organ. But in the highest organization, each tissue is found in many organs, and each organ consists of many tissues. Muscle, nerve, and bone, for

Formation of organs.

[1] P. 107.

[2] If I understand Dr. Beale, he believes rapidly-growing morbid growths, of the cancerous type, to be caused by cellular growth being in such excess as to destroy the power of development. (See Beale's edition of Todd and Bowman's Physiology, pp. 92, 130.) It is known that cancer consists of "fungous" cellular tissue of very low organization. It is very interesting, and to my mind satisfactory, thus to find this most fearful of all classes of disease traceable, like commoner diseases, to a disturbance in the balance, or harmonious action, of the different vital functions.

instance, are found alike in the head, in the limbs, and along the spine of man. It is self-evident that the formation of organic compounds must be anterior to any formation of tissues or organs. But it cannot, I think, be said that the formation either of tissues or of organs is in any sense anterior to the other. It is to be remembered also, that, as already stated, there are some tissues, at least in animals, which do not originate in cells, but are formed by the direct transformation of structureless sarcode.[1]

Classification of vegetative functions.

From the point of view which I have taken in the last few paragraphs, the vegetative functions may be classified as

Formation of organic compounds;
Formation of tissue; and
Formation of organs:

of which the first is chemical, and the others may be called structural.

Animal functions.

We now come to the animal functions, which essentially consist in the transformation of energy.[2] As I aim only at drawing an outline, not at filling it up (which, indeed, in the present state of science, no one, probably, is competent to do), I will say nothing of the production of heat, electricity, and light by animals; I will speak, as I did in the last chapter, only of the motor functions, which are the characteristic ones of unconscious animal life: and of the sensory, conscious, and mental functions.

Four grades of the motor function.

In the ascending scale of nature, there are four grades of the motor function, differing from each other according to the circumstances under which the transformation of vital into motor energy is determined.

Spontaneous motion.

The first of these may be called the spontaneous. To this class belong the circulation, or rather rotation, of the almost fluid contents of vegetable cells, which is often to be seen under the microscope: the motions of the germs of low aquatic organisms, vegetable as well as animal, through the water (which have often caused them to be

[1] P. 127.

[2] See the chapter on the Dynamics of Life (Chapter X.) for the relation between conscious nervous action and the transformation of energy.

mistaken for microscopic animals), and that "ciliary" motion, which is the only motor action of sponges, and appears to be universal in the animal kingdom. Motions of this class are found where there is no nervous system, as in plants and sponges: and even where there is a nervous system they are quite independent of nervous agency, as is proved by the fact that the "cilia" in man and the higher animals continue in motion long after death, and even when they are detached from the body. So far as has been ascertained, they are also independent of any structure, but are simply due to the primary power of living matter to transform energy. No structure has been as yet discovered in the "ciliated cells" of even the highest animals.[1]

Cilia.

The next kind of motor action is that which is performed in response to a stimulus, and not accompanied with sensation. This is generally confined to animals, though there are instances of it among plants, as in the sensitive-plant and in Venus's fly-trap. The fact that it is found among vegetables at all proves that it cannot be essentially dependent on nervous action; and a similar proof is afforded by the Hydrozoa among animals, which have no vestige of a nervous system, yet spontaneously close on their food when it touches the tentacles. And all muscular fibre appears to have the power of contracting in response to various kinds of stimuli, such as electrical excitement,[2]

Motion in response to a stimulus,

in plants:

in animals without nerves:

[1] Carpenter's Comparative Physiology, p. 125. See also Carpenter's Human Physiology, p. 674.

Cilia are minute hair-like projections, which are in constant and rapid motion during life. Their use varies according to position: in animalcules and in the Ciliograda they are organs of motion; in very many animals they are used to produce currents in the water, sometimes for the purpose of bringing food, sometimes to keep the respiratory organs bathed with fresh supplies of water. In land animals, their only known function is to produce currents of fluid towards the outlets of the body. If cilia are to be called organs, they are organs the formation of which is independent of any differentiation of the tissue.

[2] Thus in Helmholtz's experiment (p. 138) to determine the velocity of the nervous current, electricity is seen to be capable of acting on muscle directly, as well as of acting on it through the means of nerve; causing the muscle to contract in either case.

the application of some poisons, as well as to the stimulus of a flow of nervous energy. But where there is a nervous system all muscular action appears to be normally produced by nervous agency. This is true even of the action of the heart, which has a nervous system of its own. When motion takes place in response to a stimulus and through nervous agency, the mechanism is as follows:—

through nervous agency.

Nervous mechanism.

Every nerve-fibre is connected—at least at one extremity—with a ganglion. Different nerve-fibres have different functions, according to the organs with which they are connected at their *outer* terminations (their ganglia being called their *inner* terminations): some are *centripetal*, and transmit stimuli from without inwards to their ganglia; others are *centrifugal*, and transmit motor impulses from the ganglia outwards to the muscles.[1] All motor action which is determined by nervous agency is a complex fact, involving the participation of at least two nerve-fibres and a ganglion. When motion is caused by a stimulus, the stimulus—which may consist, for instance, in the contact of something that irritates the skin, or in the presence of food in the mouth—produces a flow of nervous energy along the nearest centripetal fibre to its ganglion. The ganglionic cell that receives the stimulus communicates it to another cell in the same ganglionic mass, or to another ganglion. Some action takes place among those cells, which determines the flow of a current of nervous energy outwards from the ganglion, along a centrifugal or motor

Two sets of nerves.

[1] *Centripetal* and *centrifugal* are, I think, better words than *afferent* and *efferent*, which Dr. Carpenter uses.

It is doubly inaccurate to use the words sensory and motor in this sense. All the sensory nerves are no doubt centripetal, but the facts of reflex action stated in the text show that there are centripetal nerves which are not sensory. And though centrifugal nerves are necessarily motor, yet they may be sensory nerves also. I agree with Mr. Lewes in thinking it most probable that the motor nerves are the seat of the muscular sense, or sense of muscular action. Thus some centripetal nerves are sensory, and others are not; while all centrifugal nerves are motor, but some are sensory and others are not; for the action of a voluntary muscle is accompanied by the muscular sense in its nerves, but the action of the muscles of the heart and stomach, in health at least, produces no sensation.

fibre to the muscle in which the motion is to be produced, in order to make the right response to the stimulus.

Reflex action.

Such actions as these are called reflex, the nervous action being, as it were, reflected back from the ganglion. There can be scarcely a doubt that this is the only kind of nervous action in those animals which have a nervous system in its most rudimentary form—as, for instance, in the lower mollusca. As we ascend in the animal scale, the proportion of purely reflex actions appears to become constantly smaller; but even in man those muscular actions which minister the most directly to the vegetative life are of this kind. The actions of the heart, lungs, and stomach are reflex, being independent of sensation or will: the stimulus to action is given in the heart by the flowing in of the blood; in the lungs, by the flowing in of the air; in the stomach, by the contact of the food. And actions which are normally performed in obedience to sensation or will may become reflex: thus, if the spinal cord (which is a vast bundle of nerve-fibres, accompanied with ganglionic cells) is so injured as to destroy all nervous connexion between the lower extremities and the brain, the lower extremities cease to have any sensation, or to be under the control of the will; but the ganglionic masses of the spinal cord act as a "reflex centre" for them; and if the centripetal nerves are excited, as by tickling the soles of the feet, the spinal cord, on receiving the unfelt stimulus from the centripetal nerves, will reflect it back along the corresponding centrifugal nerves in the form of a motor impulse, producing convulsive motions of which the patient is totally unconscious.

Reflex action in heart, lungs, and stomach.

Reflex actions performed abnormally.

Consensual action

Next is what Dr. Carpenter calls consensual action: that is to say, muscular action depending on sensation, but involuntary; such as closing the eyes against a flash of light, or shrinking from the contact of anything that cuts or burns. Both reflex and consensual action are in response to a stimulus; but reflex action, as we have seen, is independent of any sensation, while the stimulus to consensual action consists in sensation.

Cause of sensation unknown.

We do not know, and it is not probable that we ever

shall know, on what the difference depends between the sensory and the merely reflex ganglia: in other words, why it is that some ganglia become sentient when they are acted on by their nerve-fibres, while others are without that wondrous property. The microscope has not revealed any difference between the ganglia, or between the nerve-fibres, which are thus so unlike in their powers.

Voluntary action: depending on nervous stimulus.

Last and highest is voluntary muscular action. This, also, as well as reflex and consensual action, in all probability depends on the stimulus of currents of nervous energy acting on the ganglia which are in communication with the motor nerves; but in the case of voluntary action, the exciting currents proceed, not, as in the other two cases, from the outer extremities of nerve-fibres, but from within the brain itself. I shall have to say more on this subject when I come to treat of Mind.

It is to be observed that no line can be drawn between consensual and voluntary action. Many actions, such as closing the eyes or coughing, may be either the one or the other; and an action that was at first voluntary may become consensual from habit; as, for instance, the act of walking, which, though it has to be almost consciously learned by the child, soon comes to be carried on in response to the sensation of touching the ground with the feet, without needing a fresh determination of the will at

Instinct.

every step. It is proved by the facts of instinct that many actions which are voluntary in man are consensual in many, if not all, of the lower animals. Thus, chickens pick up grains, and ducks run to the water, the moment they are out of the egg.

Summary.

We thus enumerate four kinds of motor action in organisms, according to the way in which it is produced, as follow:—

1st. Spontaneous.
2d. Produced by an unfelt stimulus, or reflex.
3d. Produced by a felt stimulus, or consensual.
4th. Voluntary.

It is interesting to observe how these functions are successively added, the one to the other, in the ascending

organic scale. Thus, all organisms whatever perform spontaneous motions: all animals, except perhaps some of the very lowest, move in response to a stimulus: all sentient animals move in response to sensations, and probably all animals that have any mental power higher than mere sensation are capable of voluntary motion.

Sensory functions.

We now come to the sensory functions. We have seen that the nervous system is, essentially and primarily, a part of the animal apparatus for the transformation of energy; that it is in the highest degree probable that every action of the nerves whatever, as well as of the muscles, is accompanied by a transformation of energy; and that in sensation and thought the transformation of vital energy is probably into heat.

Mind.

I have enumerated four successive gradations of the motor functions. The gradations of the sensory functions are almost infinite: beginning with simple sensation, and going on through those functions of memory, perception, and thought, which constitute Mind. All these have their starting-point in sensation: they consist of simple elements, which, however, form endlessly varied combinations. In the logical order, this would be the place for a treatise on mental science; but I prefer to keep to the customary order, and, so far as possible, to treat of mental science apart, and after biology; and for the present I will enumerate all the sensory functions under the two heads of sensation and mind.

Tabular summary.

All the organic functions may consequently be enumerated in the following tabular form.:—

Formative or vegetative functions, essentially consisting in the transformation of matter.	Chemical.	Formation of organic compounds.
	Structural.	Formation of tissue. Formation of organs.
Animal functions essentially consisting in the transformation of energy.	Motor.	Spontaneous. Reflex. Consensual. Voluntary.
	Sensory.	Sensation. Mind.

Development of functions by differentiation.

I hope I have now said enough to make intelligible the statement at the beginning of this chapter, that vital functions are developed one out of the other by gradual differentiation. Formative, motor, and sensory functions are no doubt too fundamentally distinct to be produced by differentiation the one from the other.[1] But within each of these three groups there is so perfect a gradation between the various kinds, or rather the various grades, of functions, that it is easily seen how one may be developed out of the other. In the vegetative or formative series, the first and simplest functions are the chemical ones. Above these are the structural functions, the lowest and simplest of which is the formation of cells. Now cells are formed by a chemical differentiation between the constituents of the inside and the outside of the cell; so that the chemical function here passes into the structural one. And a gradation is manifestly possible from the formation of the simplest cellular tissue to that of the most complex organ. In the motor series, the gradation is decided: it is impossible to say where the one grade ends and the other begins. The same is equally true of the sensory, though perhaps less obvious: but I defer this part of my subject till I come to treat formally of Mind.

In the next chapter I shall have to state the peculiar laws of life on which the possibility of this gradation depends.

[1] See Note B (p. 166).

NOTE A.

We have seen that all organisms whatever have the power of effecting chemical transformations in matter, but the power of decomposing carbonic acid and forming the primary organic compounds belongs to vegetables alone. It is not, however, a correct account of the matter, to say that vegetables separate carbon from the inorganic world, and that the animals which eat the vegetables give it back to the inorganic world again in the carbonic acid of their respiration. The truth is that the formation of carbonic acid by respiration, which is a slow combustion, is a function of all organisms whatever,[1] and probably of every part of every organism that continues to live (not of such tissues as nails and hair). The opposite function of decomposing carbonic acid and assimilating the carbon, on the contrary, belongs no doubt to vegetables only; but it does not belong to every part of a vegetable, nor to every vegetable species, nor to any vegetable at all times (any air-breathing vegetable at least, for it may be different with sea-weeds, the deep-growing species of which are less dependent on light). The power of decomposing carbonic acid does not belong to germinating seeds, for they give off carbonic acid just like respiring animals. It belongs only to the green parts of plants, and to them only when exposed to light; and there are tribes of plants that have no green parts, and do not decompose carbonic acid at all, but obtain their carbon, like animals, by feeding on other plants. Such are the fungi, which obtain their carbon mostly from decaying vegetable matter; and also the Orobanchaceæ, a tribe of flowering but leafless plants which are parasitic on other plants, and live on their juices.[2]

Only vegetables decompose carbonic acid.

All organisms produce it.

Only the green parts of vegetables decompose it, and only in the light.

Vegetable tribes that do not decompose carbonic acid.

If then vegetables have motor actions like animals, and if there are whole tribes of vegetables which, like animals, do not decompose carbonic acid, and if the lowest classes of animals have no muscles nor nerves, what is the distinction between the kingdoms? I reply, that I do not believe there is any absolute and certain distinction whatever.

No absolute distinction between vegetables and animals.

[1] A possible exception to this is mentioned in note 2, p. 85.

[2] Carpenter's Comparative Physiology, p. 732. It is to be observed, however, that the copper beech, and other plants with leaves that are not green, decompose carbonic acid in the usual way.

NOTE B.

FORMATIVE AND MOTOR FUNCTIONS.

Actions in Foraminifera at once formative and motor.

I do not know that it ought to be said that there is no gradation between the formative and the motor functions. The Foraminifera, and some other Rhizopods, put forth projections of the sarcode substance of the body, called pseudopodia, which are, at least as to function, temporary tentacles. May not these be truly homologous with the permanent tentacles of the Hydrozoa? If so, the putting forth and retraction of the pseudopodia, which are manifestly motor actions, are also to be classed as formative, forming the transition from the formative to the motor functions. What supports this conjecture is the fact, that in *gromia* the pseudopodia are only formed at one end, but in *amœba* they are formed on any part of the surface of the body; just as in *hydra* the tentacles all form a ring round the mouth, but in some of the compound Hydrozoa there are tentacles on various parts. Dr. Wyville Thomson appears to share this view. He says: "I am strongly inclined to regard cilia as locomotive pseudopodia, and to consider them special to the sarcode [living but structureless] element." (Embryology of the Echinodermata, *Natural History Review*, Oct. 1864.) Cilia are certainly in some degree permanent organs.

CHAPTER XV.

THE LAWS OF HABIT.

I HAVE to begin this chapter by stating in what sense I intend to use the word Habit.

Meaning of the word habit.

We generally use the word with special reference to the mysterious border-land between the conscious and the unconscious functions. Thus we say, that such an action as using some particular tool, for instance, is conscious at first, and afterwards becomes habitual. This is one of the most important cases of the law of Habit, and for the purposes of human education it is all-important: but it is only one case of the law. Among animals in the wild state there is a great variety of instincts to which this explanation will not apply. To mention that which Darwin justly calls "the most wonderful of all known instincts," we cannot suppose that the bee, in building its hexagonal cells, has, or ever had, any conscious knowledge of those geometrical properties of the hexagon which make it the most suitable form at once for convenience and for the economical use of wax. If, as I think we must, we class this and other purely unconscious instincts as cases of habit, the definition of the word habit must be greatly extended. Habitual actions, under any possible definition, include all mental and mentally determined actions which are not purely voluntary. But, if we are to extend the definition of habit so as to include under the denomination of habitual such purely unconscious instincts as that of the bee, we must include under that denomination all motor actions whatever that are characteristic either of organic species or of particular individuals. And this is

Conscious actions becoming habitual.

Unconscious instinct of the bee.

Motor habits of climbing plants.

true not of the motor actions of animals only, but of those of vegetables as well: for instance, those remarkable motions of some climbing plants that Darwin[1] has lately described, the tendrils of which swing about until they touch something, and then clasp themselves round it. Here there is no possibility of conscious purpose on the part of the plant itself, and yet the motions of its tendrils are as truly habitual and instinctive as those of a serpent's body, or of a chameleon's feet and tail, in grasping the branches that they climb.

Motor and mental habits.

Thus all mental and all motor actions are to be classed as habitual, excepting only those which, in man and some of the most intelligent animals, are directed by a voluntary impulse in pursuit of a conscious purpose.

Formative habits.

But a still more extensive use of the word habit is sanctioned by usage, and, in my opinion, with perfect accuracy. Physicians speak of a habit of body; and botanists speak of the habit of a plant, meaning by that expression such characters as whether the stem is herbaceous or woody, whether the leaves are fleshy or thin, &c. Characters of this kind belong not to the motor but to the formative functions—not to the animal, but to the vegetative life; yet I think it is perfectly accurate to class such characters as habits, and to say that they come under the laws of habit. I believe that all classes whatever of vital functions come under these laws, whether the functions are formative, motor, or sensory; whether vegetative, animal, or mental. Formative and motor actions are inseparably connected. To mention one instance out of an innumerable number:—"Ampelopsis quinquefolia, or

Virginian creeper.

the Virginian creeper, avoids the light, uniformly seeking dark crevices on broad flat surfaces, as a wall, a rock, or the trunk of a tree. The tips of the tendrils, brought into contact with such a surface, swell out, and form in a few days those well-known discs or cushions by which the plant firmly adheres to its support."[2] The moving of the tendrils in search of some suitable dark crevice

[1] See the Quarterly Journal of Science, April 1866, pp. 257, 258.

[2] Ibid. p. 258.

in order to fix themselves is a motor action; the formation of the cushions is a formative action; yet both are characteristics of the species, and the one is surely as much a habit as the other.

I am, however, aware that the mere definition of the right use of a word, however needful and however accurate, ought never to be confounded with the ascertainment of a natural law. We ought carefully to guard against the error of making any assertion as to matter of fact, in the disguise of the definition of a term. I now go on to state what I conceive the laws of habit to be.

All vital actions whatever come under the laws of habit: and none but vital actions do so. By *vital* actions I mean all those actions which organisms perform in virtue of being alive: and when I speak of *actions*, I include all functions, even those in which the organism is usually said to be passive, as in sensation.

All vital actions become habitual,

The definition of habit, and its primary law, is that all vital actions tend to repeat themselves; or, if they are not such as can repeat themselves, they tend to become easier on repetition.

tending to repeat themselves.

It may appear that this law is in no way peculiar to the actions of living beings: for there are many inorganic actions that tend to repeat themselves, and to become easier on repetition. For instance: flowing water generally makes a channel for itself, and tends to flow afterwards in the same channel; and if a piece of paper has been once folded, it is easier to fold it again in the same folds than in new ones. But there is a fundamental difference between such cases and all true cases of vital habit. The cases just mentioned are cases in which the direction of action is determined by mere change of form: the water tends to flow in the channels, because their form is suitable; the paper tends to lie in particular folds, because it has acquired their form. But let the channels be filled up, or let the folds be taken out of the paper by hot pressure, and these tendencies will be utterly lost.

Apparent inorganic habits fundamentally different.

But, it may be said, may not organic habits be the result of changes of the same kind? May not the formative,

Theory that organic

habits depend on structure,

motor, and mental characteristics of every living species and individual be due to peculiarities of structure so minute and subtle as to elude the microscope?[1]

I reply, that this would be a most plausible view if habitual characters were confined to the individuals in which they are formed. But this is not the case: all habits (that is to say, according to my definition of the word habit, all characters whatever) become, or tend to become, hereditary. This is as certain as any proposition can be which cannot be proved by experiment, but rests for its proof on cumulative evidence. Now, we have seen that an embryo consists, not of a miniature of the parent form, but of a small mass of germinal matter, without structure or form, but having an inherited tendency to reproduce the structure, form, and all the habitual characters of its parents. This truth can be expressed in the language of the theory of habit only by saying that every habitual tendency passes, or tends to pass, from the organ which is its seat (as, for instance, the brain is the seat of mental habits) into the germinal matter of the body: and when a portion of that germinal matter is thrown off in order to produce a new individual, it imparts its habitual tendencies to the new individual. It is, no doubt, conceivable that if our microscopes were powerful enough, they might reveal some peculiarity of structure corresponding to every habitual character of the fully formed organism. But it is not conceivable that the microscope should reveal peculiarities of structure corresponding to peculiarities of habitual tendency in the embryo, which at its first formation has no structure whatever. I therefore conclude that in all habitual tendency there is something quite inscrutable and mysterious: as there certainly is in the tendency of the germinal matter of the embryo to develop into a new individual of its own species; which, indeed, is only a particular case of habitual tendency.

contradicted by embryology.

Habits become hereditary.

Habit is mysterious.

[1] This view of mental habits as depending on acquired peculiarities of nervous structure, has been lately maintained, most ingeniously and elaborately, by Professor Bain. (See the Fortnightly Review, 1st February, 1866.)

The law that all habits tend to become hereditary is subject to a very important limitation, of which I shall have to speak when I come to treat of mind.

Inherited characters appear sometimes at the same age as in the parent, sometimes earlier.

When any peculiar tendency is inherited, it sometimes appears in the offspring at the same age at which it appeared in the parent, but sometimes earlier:[1] never, probably, or only in the rarest cases, at a later age. Hereditary diseases afford many instances of both kinds of cases: of the peculiarity reappearing in the child, in some cases at the same age at which it was acquired by the parent, and in some cases at an earlier age. A remarkable instance of the habit showing itself at an earlier age, is the fact of young dogs, the parents of which have been taught to point, themselves sometimes beginning to point the first time they are taken out.[2] I agree with Darwin in attaching great importance to this class of facts, respecting the age at which variations occur, in throwing light on the origin of species.

Hereditary tendency without special habit.

There can be no doubt that even when a habit does not become hereditary, a tendency to it, or a facility for acquiring it, does become hereditary. In those cases, for instance, in which a young pointer has not inherited the habit of pointing, that habit is nevertheless more easily acquired by him than it would be by a dog whose ancestors had not been taught to point. The case of a dog

[1] Darwin on the Origin of Species, 4th ed. p. 14. (It is from the fourth edition I shall always quote.)

[2] The following is a very striking instance of the same kind: "Sir C. Lyell mentions that some Englishmen, engaged in conducting the operations of the Real del Monte Company in Mexico, carried out with them some greyhounds of the best breed to hunt the hares which abound in that country. It was found that the greyhounds could not support the fatigues of a long chase in this attenuated atmosphere, and before they could come up with their prey they lay down gasping for breath; but these same animals have produced whelps, which have grown up, and are not in the least degree incommoded by the want of density in the air, but run down the hares with as much ease as do the fleetest of their race in this country." (Carpenter's Comparative Physiology, p. 987.) In this case the power of breathing with facility in a rare atmosphere, which only had a tendency to be produced in the parents, was congenital in the offspring.

which is easily taught to point because his ancestors have been taught before him, is similar to that of a man who once learned to practise an art or to speak a language, and, though he has forgotten it, can learn it again much more easily than he could if he had never known it. The fact of the dog's ancestors having learned to point gives the same facility to the dog himself in learning it, which the fact of the man having once learned an art gives him in learning it again.[1]

Habit is changeable,

Another most important law of habit must be formally stated, though it is implied in what has been said about the acquisition of new habits. It is, that all habits are in some degree changeable. New habits are constantly produced by change of circumstances, and by education, which indeed is only a special and artificial set of circumstances: and this could not be the case if habits were not in some degree changeable.

and spontaneously variable.

But besides the *changeability* of habit as the result of changing circumstances, there is a certain amount of *spontaneous variability*, which does not depend—at least not directly—on change of circumstances. No child is exactly like either of its parents, and no two children of the same parents are exactly alike. These differences might be attributed to differences of circumstances acting on the offspring through the parents; but such an explanation is shown to be at least insufficient, by the fact that the same differences are found to exist between twins, though, in general, in a somewhat less degree than between other children of the same parents; and it is obvious that twins have been subjected to precisely the same influences. The same is very generally true of those domesticated races of animals which produce several young at a birth.

It is a most important, and a much debated question, whether there is any limit to spontaneous variation. Variation in a single generation is beyond doubt confined within very narrow limits: no such variations appear to be possible (among the higher animals and vegetables at least) as would be implied in "gathering grapes of thorns

[1] See Bain on the Emotions and the Will, Appendix C.

and figs of thistles." But I agree with Darwin in believing that there is no limit to the possible extent of variation acting cumulatively, if only a sufficient number of generations is allowed;—no limit, I mean, as to the possible *extent* of change: there are, I believe, definite laws as to its *direction*. Of these laws we know but little; it is, however, a very important truth, that variation does not go on equally in all directions at once, but takes place in particular directions at particular times: in other words, organisms acquire *habits of varying* in particular directions; and these habits of varying are characteristic not only of individuals but of species and genera; perhaps we may say, of whole classes. As an instance of this—not by any means the strongest instance I can think of, but the most familiar—may be mentioned the well-known fact that the acquisition of any power that depends on habit makes it easier to acquire other powers of the same kind: thus, the mastering of one language makes it easier to master other languages. This is not simply a case of a habit perpetuating itself. The knowledge of any language consists in the habitual connexion in the mind between the words of the language and the ideas they represent, so that the one will recall the other without effort; and these connexions are different for every different language. But though the habitual connexions are different, the habit which is cultivated in acquiring them for one language facilitates their acquisition for another: a habit has been acquired of acquiring a particular kind of habits. This law, that organisms acquire a habit of varying, or, in other words, of altering their habits in particular directions, is shown by Darwin to be true of the formative functions as well as of the motor and mental ones; and he has clearly perceived its great importance in accounting for the origin of species. I shall have more to say on this subject in a future chapter.

I believe in no limit to variation.

Habits of varying.

Instance of acquiring languages.

Habits, as we have seen, are formed and strengthened by repetition of the acts. This, indeed, is only a statement of the elementary law of habit. The converse is also true: habits are weakened, and may at last be

Habits are weakened

and destroyed by disuse.

destroyed, by discontinuance of the acts; as, for instance, when we forget how to speak a language, or to practise an art, which we once knew but have discontinued. From these two laws—that habits are strengthened by repetition of the acts, and are weakened by their discontinuance—it follows that the strength of any particular habit, other things being equal, depends on two different factors: one, the length of time during which the habit has been exercised; the other, the shorter or longer time that has elapsed since it has been exercised. The effect of these two factors, however, is not the same in kind. The *present strength* of any particular habit depends chiefly on its having been recently exercised; but the *tenacity* of a habit, or, in other words, the difficulty of weakening or destroying it by disuse, is a different thing from its present strength, and the two do not stand in any constant proportion to each other. The tenacity of a habit depends on the length of time during which it has been exercised: that is to say, the longer a habit has been in forming and strengthening by exercise, the longer time it will take for it to be weakened or destroyed by disuse. These facts are familiar. Every one knows that habits of long standing are not easily lost; and the most tenacious habits are those which belong to the species, and have been exercised not merely through a lifetime but through an unknown number of generations.[1] Hereditary characters, indeed, are seldom —I believe never—destroyed by disuse during a single generation, though they may be destroyed by disuse during many generations: the domestic fowl and duck, for instance, have nearly lost the power of flight by long-continued disuse. Thus the law of the hereditary transmission of habit is equally true of its destruction as of its formation.

Strength of a habit depends on time *during which* it has been exercised, and on time *since* it has been exercised.

Present strength of a habit.

Tenacity of a habit.

Hereditary characters are the most tenacious.

[1] I am surprised that Darwin should say, "I do not wish to dispute the truth of the proposition that inheritance gains strength simply through long continuance, but I doubt whether it can be proved." (Variation under Domestication, vol. ii. p. 26.) That inheritance should so gain strength appears to me at once a necessary consequence of the laws of habit, and a necessary inference from the general truth that the characters of the variety are more variable than those of the species.

For the sake of clearness, I have stated the law of the weakening and destruction of habits by disuse as if it were an independent law. But in reality it is not so: it is a mere case of the elementary law of habit. The elementary law is, that by acting in any way a habit is formed of acting in that way: and it is a mere case of that law, that by ceasing so to act, a habit is formed of not so acting; or, what is the same thing in other words, the habit of so acting is lost. The only really elementary laws of habit are these three: that all actions, whether formative, motor, or mental, tend to become habitual; that all habits tend to become hereditary; and that all habits are in some degree variable.

Weakening of habits by disuse is a case of the general law.

All actions become habitual: all habits become hereditary: all habits are variable.

As I have stated, the present strength, or what may be called the *prominence* of a habit, depends on its having been *recently* exercised; but its *tenacity* depends on what is quite different, namely, the *length of time* (millions of generations, it may be) during which it has been exercised. These simple and well-known truths are little more than obvious corollaries from the elementary laws of habit; but on them depend some very remarkable and rather intricate interactions between different habitual characteristics. A habit which has been much exercised during a comparatively short time may be very prominent, but it cannot be very tenacious; and it may be lost by disuse during a period of time which is too short to produce any perceptible effect in destroying a more tenacious, though perhaps less prominent habit. Cases of this kind are no doubt difficult to identify, but it certainly is possible that new mental and moral habits, amounting to a change of character, may be acquired as a result of education and circumstances, and may afterwards disappear with advancing age and under new circumstances, while the original, perhaps hereditary, character reappears.

Reappearance of old habits.

A tenacious habit may appear to be lost when it is in reality only latent. A latent habit is one which, though not obvious, may at any time reappear; sometimes spontaneously, sometimes by placing the organism in the same circumstances as those which produced the habit at first.

Latent habits.

It is a well-known instance of this, that when the use of an art, or of a language, has been laid aside so long that, at the first attempt to recommence it, it appears to be totally lost, a little practice will often prove sufficient to regain it in a mere fraction of the time that would be necessary to learn it if it were really new. This is a case of the rapid reappearance of a latent habit under favouring circumstances. The most remarkable instance of the spontaneous reappearance of a habit is the reversion of individuals, and, as I believe, of species, to ancestral characters after the lapse of many generations; which, according to general belief, sometimes occurs in the human race, and beyond all question does occur among domesticated breeds of animals.[1] The characters of the breed which have arisen under domestication, and consequently are of later date than those of the species, are *prominent* habits: those of the species which reappear in these cases of reversion are *tenacious* habits, which may, as it were, be overlaid and concealed by the later acquired ones for a great number of generations, and yet reappear at last. I shall have to speak, further on, of the importance of this class of facts in accounting for the characters of species.

Reversion to ancestral characters.

In the chapter on the Dynamics of Life I have stated my belief that the differentia of life consists in certain powers, which all living beings possess, of transforming matter and energy. Except the laws of those transformations, I believe the elementary laws of habit are the only laws of life which are at once elementary and universal. I regard these as ultimate laws, like the laws of gravitation and of the affinities of the chemical elements, and, like them, incapable of being referred to any others.

Laws of habit are elementary and universal laws of life.

It is an important result of the laws of habit, that while active habits are strengthened by the repetition of the act, passive impressions are weakened by the repetition of the impression.[2] Both of these facts are perfectly familiar:

Active habits strengthen, passive impressions weaken, by repetition.

[1] Darwin's Origin of Species, pp. 15, 190. The most remarkable instances, both of variation and of reversion, are those of the domestic pigeon.

[2] So far as I am aware, this remark was first made in Butler's "Analogy of Religion."

every one knows that being habituated, or accustomed, is an explanation alike of being able to do what an unaccustomed person could not do—as, for instance, to execute a difficult piece of music; and of being able to resist what an unaccustomed person would have great difficulty in resisting, such as great heat or cold, and impressions of particular kinds of horror or fear. These effects are opposite, and it might appear that the weakening of impressions by repetition is the result of a distinct law, opposite in its character to the general law of habit; but it is in reality a case of that law. A passive impression becomes weaker by repetition, because the organism acquires the habit of not responding to it. A passive impression means one which is not followed by action. An impression which is not followed by action differs from one which is followed by action, not in the nature of the impression, but only in the response the organism makes to it. The same impression, acting on two similar organisms, may, according to circumstances, remain a merely passive impression on the one, and may become an active stimulus to the other. To mention a familiar instance: two men hear the same loud bell in the morning; the one is accustomed to awake and get up at the sound, and he awakes; the other is accustomed to disregard it, and he disregards it and sleeps through it.[1] This view is supported by the fact, that it is possible to increase the strength of merely passive feelings —feelings, that is, which do not lead, and are not meant to lead, to action—by the habit of brooding over them; and, without so much mental action as is implied in brooding, it is possible to give a mastery over the mind to the passive emotions, especially to fear, merely by acquiring a habit of yielding to it.[2]

Both are cases of one law.

Instance of the effect of an accustomed sound.

All this is familiar; but, so far as I know, it has not yet been clearly pointed out that the law of passive impressions weakening by repetition, while active habits strengthen

[1] I have met with this illustration of the law somewhere in Whately's writings.

[2] See Bishop Fitzgerald's Note B to Chap. V. of Butler's "Analogy of Religion."

The same is true of the uncon-scious life. from the same cause, is not confined to mental and voluntary actions, but has its foundation far down in the unconscious life. Effect of medicines and stimulants. One instance of this is the well-known fact, that the power of medicines and stimulants is diminished by constant use. Action of the heart under a stimulus. Another and very remarkable instance of the law is the way in which the heart responds to a stimulus; such as a blow, or a sudden fright, or an electric shock. The first effect of a stimulus on the heart is to cause a momentary cessation, or at least slackening, of its action. If the shock is violent enough, it causes death; but otherwise the effect passes away, and is followed by a quickening of the heart's action—the well-known "beating of the heart" produced by a shock. If the stimulus is repeated, supposing its intensity to be the same, its effect will become less with every repetition,[1] showing that the heart is acquiring the habit of not making any response to it—just like the sleeper who acquires the habit of making no response to the bell. General law respecting passive impressions. From such instances as these—which are clearly not exceptional, but normal—I think we may infer, not only that, as already stated, organisms are capable of acquiring a habit of not responding to stimuli, but also that they always do form such a habit, unless there is some cause to determine them to form the opposite habit; namely, the habit of making a response. A still more remarkable instance of this law, and one where neither voluntary determination nor nervous action of any kind can come into play, is afforded by the motions of those climbing plants which have been already referred to. Instance of climbing plants. It is stated by Mr. Darwin, that a thread weighing no more than the 32d of a grain, if placed on a tendril of the *Passiflora gracilis*, will cause it to bend; and merely to

[1] Claude Bernard, in *Revue des Deux Mondes*, March 1, 1865. The stimulus used in such experiments is that of an electric current sent through the pneumogastric nerve. The heart, in relaxing under a stimulus, acts differently from other muscles, which contract under the same; the arteries, which have a muscular coat, contract under a stimulus, such as drawing the point of a needle over the skin without making a scratch; but though this effect is opposite in kind to that produced by a stimulus on the heart, yet, like the latter, it is weakened by repetition. (Carpenter's Human Physiology, p. 231.)

touch the tendril with a twig causes it to bend; but if the twig is at once removed, the tendril soon straightens itself. But the contact of other tendrils of the plant, or the falling of drops of rain, do not produce these effects—proving, apparently, that the tendrils have acquired the habit of disregarding these:[1] a wonderful instance of vegetable instinct.

Organs grow with exercise.

It is a most important fact that organs increase with exercise, not only in functional power, but also in size; while, conversely, organs that are disused, in whole or in part, diminish, not only in functional power, but also in size: and such modifications, like all others, are capable of becoming hereditary. It is difficult to prove that this connexion between the habitual exercise of an organ and its magnitude is true of the organs of the nutritive life, because most of them are incapable of any excessive stimulation without producing disease; but I think the "expansion of the chest" which properly-directed exercise produces, shows it to be true of the lungs. It is well known to be true of the muscles; and though the evidence is less direct, I think it is scarcely possible to doubt that it is so of the organs belonging to the nervous system—that the brain, for instance, is increased in functional power and in size by successive generations of mental cultivation.[2]

Lungs, muscles, and brain.

Laws of habit are true of both mind and body.

It will be noticed by the reader that I have taken the instances of habit which I have quoted, indifferently from among mental and bodily habits, or, as I prefer to say, from among conscious and unconscious habits; showing how the same laws of habit govern both the conscious and the unconscious life.

Laws of habit do not account for every particular habit.

It is to be observed that the laws of habit do not account for the origin of every particular habit. This, however, is not because of any imperfection in our knowledge of the subject: it is because the laws of habit, by the definition of the word, have to do only with the repetition of actions and the perpetuation of tendencies; but they do not necessarily throw any light on the cause of the first of a series

[1] Quarterly Journal of Science, April 1866.

[2] See Note at end of this chapter.

of actions that has become habitual—just as the laws of motion, though they are perfectly well understood, throw no light on the origin of force. We know that in man, and in a less degree among the more intelligent animals, a great variety of actions are capable of becoming habitual that were voluntary in their origin. On this possibility the whole art of education is founded. But this explanation will evidently not apply to the facts of what I have called spontaneous variation; nor will it apply to any formative habit whatever, nor to such motor habits as the cell-building instinct of the bee, or the turning and twining instinct of the *Passiflora gracilis,* mentioned above. By the definition of habit that I have adopted, all specific characters are habits; and, in this sense, the question of the origin of particular habits includes the whole vast and enigmatic subject of the origin of species. But, little as that subject is understood, recent research and speculation have let a few rays of light into the darkness.

Voluntary actions may become habitual.

This will not account for all habits.

Question of the origin of species.

Summary. We may thus sum up the laws of habit:—

Habit. All vital actions—formative, motor, and mental—tend to become habitual.

Hereditary transmission. All characters tend to become hereditary. An acquired character, when transmitted to offspring, appears sometimes at the same age at which it appeared in the parent, sometimes earlier.

Variation. All characters are in some degree variable, and particular characters may acquire a habit of varying.

The foregoing three are the *elementary* laws of habit; the following are derived as corollaries from them:—

Disuse. Habits, being formed by use, are weakened and destroyed by disuse.

Prominence. The *prominence* of a habit, or its present strength, depends on its having been *recently* exercised.

Tenacity. The *tenacity* of a habit, or the difficulty of destroying it, depends on its having been *long* exercised.

Consequently, a prominent habit may disappear, while a tenacious, perhaps a hereditary one, survives it.

A habit may become latent, and reappear. The re-

appearance of habits is sometimes the result of favouring circumstances, sometimes spontaneous. Reversion to ancestral characters is a case of the reappearance of habits. Reversion.

When a stimulus is responded to, it strengthens in force with repetition; when it is not responded to, it weakens. Passive impressions.

Organs strengthen and enlarge with exercise; and, conversely, they weaken and diminish with disuse. Effect of habit on organs.

It is now time to consider, in more detail than I have yet done, the manner in which the characters of a race will be modified by changes in the circumstances under which it has to live.

Great changes are destructive.

It is a universal law, that the health, and ultimately the life, of any organism whatever will be destroyed by any very great change in external circumstances. The most obvious instances of this law are the familiar facts, that air-breathing animals will die in the water, and water-breathing ones will die in the air. These facts, however, do not throw much light on any law of life, for they admit of a purely physical explanation. It is physically impossible, quite irrespective of any law of life, that a man's lungs should breathe water, or that a fish's gills should breathe air. But, independently of physical reasons like this, all great changes are destructive of health and life. Cold regions and warm ones, moist places and dry ones, have all their own peculiar races of animal and vegetable inhabitants; and those species which are native to one kind of abode will, as a general rule, be destroyed by transplanting to a totally different one. Were it not so, differences of climate would be no barrier to the migrations of species, instead of being, as they often are, the most impassable of all barriers. In many cases we cannot say what is the reason of this inability of organisms to adapt themselves to new circumstances. Sometimes, in all probability, it is in part merely physical: for instance, animals with a coat only of hair may be unable to endure the cold of those countries where most of the native quadrupeds are clothed with fur. But this kind of reason cannot be given in every case. It is, I think, quite impossible to

This is not always physically explicable.

assign any such merely physical reason for the fact that the European race of man is unable to perpetuate itself in the climate of Bengal. I believe such facts are to be referred to the laws of habit. We have seen that every organism has a certain power of becoming habituated to impressions. This it does in two different ways: if the impression demands a response, such as to close on its prey or to run away from its enemy, the organism acquires the habit of making the right response; if it does not demand nor admit of any response, the organism acquires the habit of disregarding it. Now, exposure to a different climate from that to which an organism has been accustomed, in some cases, no doubt, produces a response in the vegetative life—as, for instance, in those animals which acquire a coat of hair better suited to their new abode; and sometimes it produces a response in the motor life, as when it determines a species to acquire the habit of periodical migration. But in many cases—probably in the vast majority—no appropriate response is possible. To use familiar language, nothing can be *done*, and the change—the unaccustomed heat or cold—must be *endured*. The organism must become habituated to the climate—that is to say, must acquire the habit of disregarding the change; and if it cannot do this, the change will destroy its health, and ultimately its life. It may not be sufficient to kill the individual; but if its health is at all injured, and this is not recovered in future generations, the race will die out of its new abode. This kind of adaptability is very different in different species: thus the horse has been successfully introduced by man into every climate, from the equator to Iceland and Siberia: the ass would perish in a very cold climate.

Organisms are destroyed by changes that they cannot become habituated to.

The reasoning in the foregoing paragraph may seem vague. I am, however, convinced that there must be some profound connexion between the two facts, that great and sudden changes in the circumstances of their lives are destructive to organisms, and that organisms are unable to effect great changes in their habits, except very gradually. The proof that there is such a connexion

Great and sudden changes of circumstances are destructive.

is strengthened by the converse facts which I have next to state.

Corresponding changes in habit are impossible.

As just stated, great and sudden changes of circumstances are destructive, and great and sudden changes of habits are impossible. I believe we might say that great and sudden changes of circumstances are destructive, *because* great and sudden changes of habits are impossible.[1] And what confirms the belief that these two laws really stand in the mutual relation of cause and effect is this further pair of laws, which evidently are similarly related to each other,—that great changes of circumstances are often not destructive, provided they are not sudden; and that great changes of habit are often possible, provided they are not sudden. I believe we may say, as before, that great and gradual changes of circumstances often are not destructive, *because* great and gradual changes of habit are possible. I do not yet wish to speak of those changes which, as I believe, have occurred in geological time; but, as an instance of a wonderful change that has occurred in historical time, I may mention the dog, which, though naturally carnivorous, has in his domestic state gradually become in great part a vegetable feeder, and has been taught to tend sheep. These changes must have taken many generations to bring about. A carnivorous animal would perish if suddenly put on a vegetable diet: not that it would disagree with him—he would die of hunger sooner than touch it.

Great changes if not sudden are often not destructive.

Corresponding changes in habit are possible.

Adaptation, how effected.

The process of adaptation—or, in other words, the effects of changes of circumstances in producing new habitual characteristics—may now be stated; not, indeed, in detail, but with some degree of precision. External changes, if of any importance, will either destroy the organism, or cause the organism to acquire new habits, so as to adapt itself to the changes. The new habits will be either active or passive. An animal may, for instance, be placed in a severer climate than that to which it is native: this may take place either

Active and passive habits.

[1] Herbert Spencer would probably say, that if the organism, or the race of organisms, is unable to readjust its internal relations to the new set of external relations, it will perish. This would no doubt be true, but I do not see that it would be in any sense an explanation.

Change of climate.

from such a change of climate as we know from geological evidence to have taken place in past ages,[1] or from the animal being transported by man and becoming wild in its new abode, or from spontaneous migration; and it is sometimes impossible to say what determines the migrations of animals. In such a case, as already remarked, the animal, if it becomes adapted to the new climate at all, and is not destroyed by it, may become adapted by acquiring either the passive habit of disregarding the cold, or the active habit of producing warm fur on its skin. Of passive habits I need say no more; but the subject of the formation of active habits, including formative ones, to meet new circumstances of life, is practically an infinite one. Suppose another instance of the same kind. In consequence of the migrations of the animals that serve as its food, a beast or bird of prey is compelled to change its mode of hunting.[2] It may need keener sight, in order to obtain its new prey: in this case, its sight will be more exercised, and will become stronger; and in the course of some generations, probably, its eyes will be enlarged. Or it may need a keener sense of smell: in this case the same changes will be effected in its olfactory organs. Or it may need greater fleetness: in that case the muscles of its legs will become stronger and larger; and, what is most important to observe, such a change as this will directly or indirectly affect the form of every part of the body—partly

Change of food.

[1] I do not mean that there is any proof of a glacial period being one of extreme cold. A *cold summer* would be enough to produce it.

[2] Migrations sometimes occur in very unexpected ways. I extract the following from the Quarterly Journal of Science, October 1864:—

"The sudden occurrence of Pallas's sand-grouse (*Syrrhaptes paradoxus*) over the greater part of Europe has attracted the attention of ornithologists, and Mr. Alfred Newton has collected information which shows that this remarkable bird, hitherto almost unknown to the European fauna, has been met with during the year 1863 in no less than 148 localities in Europe and Great Britain, tracing the invading host through 33° of longitude, from Galicia to Donegal. He regards the proximate cause of this wonderful movement as the natural overflow of the population of *Syrrhaptes*, resulting from its ordinary increase, being a bird which has comparatively few enemies, while its time of incubation is short in comparison with what it is in most ground-feeding birds."

The *Syrrhaptes* is a native of the steppes of Central Asia.

by the direct action of the pressure of the enlarged muscles, modifying the form and position of the other muscles and of the bones—partly also, no doubt, by the increased nutrition demanded by the enlarged muscles diminishing the supply of nutrition to the other parts of the body, and so compelling a diminution of their size. It is also to be observed that, besides these secondary changes, as they may be called, it is quite possible for change of habit, as the result of new circumstances, to take place primarily in two or more directions at once. Thus, for instance, the necessity of pursuing a new kind of prey, or of pursuing the same kind of prey in a different manner, as will occur when forests are destroyed, may have the effect of causing an animal to improve both in keenness of sight and in fleetness. This appears to be not only a possible, but a probable case: keenness of sight and fleetness are often united in animals, as, for example, in birds of prey.

Improvement in sight and fleetness.

In this chapter I have considered the laws of the formation and perpetuation of habit; in the next I shall have to consider the laws of its variation.

NOTE.

GROWTH OF ORGANS WITH EXERCISE.

Why do organs grow with exercise? Herbert Spencer's theory.

It appears uncertain whether the increase in size of organs that are much exercised can be accounted for by any physical cause; or whether, like the law of habit, it is an ultimate law of life, and as such inexplicable. Herbert Spencer has made a most elaborate and ingenious attempt to prove that it is entirely due to the increased flow of blood that always takes place to and through an organ in activity.[1] He makes out an exceedingly strong argument for believing that the deposit of woody substance in the vascular tissue of plants, which is the process by which woody fibre appears to be formed, is originally due to the accelerated flow of the sap in the vessels near the surface of

Woody fibre.

[1] Principles of Biology, Part V. Chaps. iv., vii., and viii.

trunks and branches that are agitated by the wind. But it ought not to be taken for granted that the case of muscular and other animal tissue is parallel to this. In plants, the waste of the tissues is very trifling, and it is probably null in vascular tissue which is filling up and hardening into woody fibre; so that an increased flow of sap may very well fill up the vessels with the substance it brings, just as drains are silted up. But in animals, especially warm-blooded animals, the waste is great and rapid; and the more any organ is exercised, the more substance it loses by waste: and it is not easy to understand why the increased flow of blood through an organ should not only increase its nutrition (which it certainly will do), but cause the nutrition to exceed the waste, so as to produce growth. Perhaps the excess of nutrition to which the growth is due may be in some way caused by nervous agency, which we know to be called into play by every vital action whatever among those classes of animals that have a well-developed nervous system. Such action of the nervous system would, no doubt, be inexplicable; but it would not be more so than its action in stimulating secretion,[1] or, indeed, than any strictly vital action whatever.

Animal tissues.

Possible nervous action in increasing nutrition in exercised parts.

The cause of the increased flow of blood to and through parts that are in exercise does not appear to be fully understood. With respect to the muscles, I am inclined to think that Herbert Spencer has assigned an adequate cause, namely, the varying pressure on the blood-vessels during muscular action. But this, obviously, will not apply to the flow of blood to the brain being greater during the waking state than during sleep, or any other flow that is directly produced by nervous action. Possibly the increased flow of blood in this class of cases may be due to the calibre of the small arteries being increased by the relaxation of the nerves that control them; but I only offer this as a suggestion.

Increased flow of blood to exercised parts,

possibly due to relaxation of the nerves of the arteries.

[1] Carpenter's Human Physiology, p. 738.

CHAPTER XVI.

THE LAWS OF VARIATION.

IN the last chapter we have seen that the habitual characters of organisms are subject to two quite distinct classes of changes, which, following Herbert Spencer, I shall call *functionally produced changes* and *spontaneous variations*. I shall have to speak, farther on, of a kind of changes concerning which it is difficult to say how they are to be classed. I have to some extent, though in extreme outline, traced in the last chapter the laws according to which changes are functionally produced, and I now go on to state the conditions which are favourable to variation. I must, however, begin by stating a set of laws that have no very obvious connexion with the subject.

Changes of habit, functionally produced, and spontaneous.

We have seen that great and sudden changes of habit are impossible, and that great and sudden changes of external circumstances are destructive to an organism. Whatever may be the connexion of these two laws with each other (and I believe it is very close), their opposites are also true: slight changes of habit are possible, and slight changes of external circumstances are beneficial to organisms. Concerning the variability of habit, I need not say anything more at present; but, as an instance of the beneficial effect of slight changes of external circumstances, may be mentioned the proverbial benefit of "change of air" —that is to say, in reality, change of external circumstances —in renewing the bodily and mental health, especially of sufferers from monotonous, depressing, or exhausting occupation; and the equally well-known benefit of "changing the seed" of cultivated plants—that is to say, bringing the

Benefit of slight changes.

Change of air.

Change of seed.

seed from a distance, instead of sowing that which has been raised in the same farm or garden.

Benefit of slight mixtures of race.

I agree with Darwin[1] in believing that there is a profound connexion between this last-mentioned law and the general law, that slight mixtures of race, or "crossings of the breed," tends to promote the health and vigour of the race. I say *slight* mixtures, because very different races will not mix at all: the pollen of a rose on the stigma of a foxglove, for instance, would produce no more effect than if it were so much dust blown off the road. And between these two extremes of kindred races which are benefited by mixture, and totally distinct races which will not mix at all, there is a wide class of intermediate cases. Sometimes, when two distinct species of plants are hybridised, seed is produced, but in less abundance than if the plant bearing it had been fertilized with pollen of its own species. Sometimes, among animals, the offspring is vigorous, but infertile, and cannot give origin to a hybrid race: the mule, between the horse and the ass, is a well-known instance of this. Sometimes offspring is produced, but is weak, and dies early; sometimes, in the case of birds, without being able to break through the egg.[2]

Mixtures of unlike races.

Slight changes are agreeable, great ones disagreeable.

There is another set of facts which I will mention here, though they are not relevant to the subject of the present chapter, because I believe they stand in the closest connexion with the laws of habit and of the effects of changing circumstances. I mean that, among conscious organisms, slight changes are agreeable, but great changes painful, or at least disagreeable. This law is a most important one in mental science.

Summary.

I have now enumerated four pairs of laws which, it is scarcely possible to doubt, stand in the closest relation to each other. They are as follow :—

[1] Origin of Species, p. 318.

[2] Ibid. p. 315. See the whole chapter on Hybridism. Darwin says, that the impossibility of obtaining hybrid offspring at all in some cases, and the infertility of such offspring in other cases, are very distinct facts : but I think it needs no proof that they are facts of the same class. In the former, we cannot obtain hybrid individuals : in the latter, we cannot obtain a hybrid race.

Habits are capable of change; but only a slight change is possible in a short time.

Changes of external circumstances are beneficial to organisms, if they are slight; but injurious if they are great, unless made gradually.

Changes of external circumstances are agreeable to the mind when slight, but disagreeable when great.

Mixture of different races is beneficial to the vigour of the offspring, if the races mixed are but slightly different; but very different races will produce either weak offspring, or infertile offspring, or none at all.

Effect of confinement to a small area.

It is a very remarkable fact, that confinement to a small area appears to have a tendency to diminish the size of a race of animals, even when there is no other evidence of diminished health and vigour. Thus, animals found on islands are frequently smaller than those of the same species found on continents; and animals bred in an aquarium are often observed to degenerate in size, even while the race continues vigorous.[1] It is scarcely possible to doubt that such diminution is caused by want of room for sufficient variety in the conditions of life, or by want of sufficient mixture of the race—in other words, by the interbreeding of too small a number of individuals—or most probably by both; though the second reason will not apply in cases where the diminution is visible in a few generations among species of organisms that are able to propagate for a long time without union of the sexes.[2]

Sexuality.

What may be called the law of sexuality in organisms—that is to say, the necessity of the union of two unlike individuals of the same species for the purpose of genera-

[1] I state these facts on the authority of Mr. (now Sir John) Lubbock's paper on the reproduction of Daphnia. (Philosophical Transactions, 1857.) The Daphnia is a small fresh-water entomostracous crustacean.

[2] Ability to propagate without union of the sexes is not the same thing with hermaphroditism. The land mollusca (snails and slugs) have both the sexes on the same individual, and yet they cannot fertilize themselves. On the other hand, no winged insect is a hermaphrodite, and yet many species produce fertile eggs without impregnation.

tion—appears to stand in the closest connexion with the law of the beneficial effect of slight mixtures of race: indeed, the former law is probably only a case of the latter. This connexion, and the whole subject of the real nature of generation, can be made manifest only by studying it among the simplest and lowest organisms.

Generation is only a modification of the general vital process.

When the generative process is studied only among the highest organisms, among which it is always sexual, the inference is natural and inevitable that generation is altogether a special function; but its phenomena among the lowest organisms show that it is only a modification of the general vital process of growth and development. I will here briefly recapitulate what I have said on its true nature in the chapter on Organic Development. Any portion of the structureless germinal matter of any organic species is capable of developing into a perfect individual of the species, when placed under suitable circumstances; but the higher the organization, the more special the circumstances are required to be in order that it may so develop. In *hydra*, a form in which there is little distinction between germinal matter and formed material, a single small fragment, if detached, and permited to remain in any place where a perfect *hydra* can live, will soon develop into a perfect *hydra*. In the vast class of the Protozoa, which are the simplest of all animals, and among vegetable tribes of equal simplicity, propagation very generally takes place by means of spontaneous division into parts. But among the higher forms, in which the life is more centralized, and the parts more mutually dependent, a portion of germinal matter, if simply detached, will not develop into a new organism, but will die; and, consequently, special generative organs are set apart, in which the germinal matter is prepared and supplied with nourishment in a particular form, for the purpose of its developing into a new organism. Among the lowest organic forms, reproduction can scarcely be distinguished from growth.

Reproduction of Algæ.

Among all Algæ—and, indeed, throughout the vegetable and animal kingdoms—cells give birth to cells. Among the lowest Algæ, in which each individual consists of but

a single cell, cells divide into cells; and when they have divided, they separate. Among forms a little higher, they adhere together after dividing, and constitute cellular tissue. When they separate, we call the result propagation; when they adhere, we call it growth: but there is evidently no fundamental difference between the two cases; they are found in nearly allied forms, and, indeed, they graduate into each other through species in which the adhesion of the cells is very slight.[1]

Simplest form of sexual reproduction in unicellular Algæ.

The reproduction just described is non-sexual; but the first and simplest form of sexual reproduction is presented by those same unicellular Algæ. There is no distinction of sex, but reproduction takes place by means of the fusion into one mass of the germinal matter that forms the contents of two cells. Among the Diatomaceæ and Desmideæ, two individuals, each of them consisting of but a single cell, place themselves together and burst: the contents of the two mix, and from their union a fresh brood arises.[2]

Its essential condition is mixture of germinal matter from two sources.

Although there is here no visible distinction of sex, yet what appears to be the essential condition of sexual reproduction is fulfilled; namely, the fusion of the germinal matter derived from two different organisms, or, at least, two different cells. In the case just described, the cell-walls, after they burst and liberate their contents, are as useless and dead as the cast skin of a snake. But in the *zygnema*—an Alga of rather higher organization, which consists of cells united into filaments, somewhat like strung beads—we meet with the first and simplest form of the distinction between the sexes. Two of the filaments—that is to say, two distinct plants—approach and lay themselves alongside each other, and the contents of the cells of one filament pass over into the cells of the other, where the union is formed which is to give origin to a new brood.[3]

Zygnema: simplest form of sexual distinction.

Purpose of sexual distinction, to increase the difference

The essential matter in sexual generation is the union of germinal matter from two distinct sources; and the primary purpose of the distinction between the sexes appears to be to increase this difference. It would be premature

[1] Spencer's Principles of Biology, vol. ii. pp. 15, 16.

[2] Carpenter's Comparative Physiology, p. 878. [3] Ibid. p. 881.

of the two sources. to say that this last statement is proved; but it certainly receives strong confirmation from the facts that Darwin has collected, and on which he justly lays great stress, concerning the fertilization of hermaphrodite organisms. Hermaphrodite animals, Many of these, as land-mollusca and earth-worms, have the male and the female organs so placed with respect to each other, that they cannot fertilize themselves, but pair, like animals with the sexes on distinct individuals. And though many hermaphrodite animals do habitually fertilize themselves, yet Darwin states, on Huxley's authority as well as his own, that among known animals there is not a single instance of the female organs being out of the reach of the spermatozoa of another individual occasionally entering. No terrestrial animal is known to fertilize itself, and among aquatic species the spermatozoa may be carried in currents of water.[1] and plants, not always self-fertilizing. With respect to plants, the evidence is even more remarkable and more decided. Most flowers are hermaphrodites; and when the remarkable discovery of the sexuality of flowers was first made, it was naturally supposed that each flower was fertilized by its own pollen. But Darwin has shown that in many cases this is impossible, in consequence of the stamens and pistils coming to maturity at different times;[2] and there are some instances of reciprocally dimorphic species of plants—that is to say, plants bearing two kinds of flowers, each of which contains both stamens and pistils; but the pistils of each form can be properly fertilized only by the pollen of the other.[3] Agency of insects in fertilizing flowers. Insects are the principal agents in carrying pollen from one flower to another; and it is Darwin's belief that flowers have been endowed with their bright colours (and, if so, no doubt with their nectar also) for the purpose of attracting insects.[4] Insects are useful,

[1] Origin of Species, p. 113. [2] Ibid. pp. 111, 325.

[3] Ibid. p. 320.

[4] Ibid. p. 239. "I have come to this conclusion," he says, "from finding it an invariable rule that when a flower is fertilized by the wind, it never has a brightly-coloured corolla. Again, several plants habitually produce two kinds of flowers; one kind open and coloured, so as to attract insects, the other kind closed and not coloured, destitute of nectar, and never visited by insects."

no doubt, not only by bringing pollen from other flowers, but also, in those flowers which are capable of being fertilized by their own pollen, by brushing it on to the stigma; and it is probably impossible in all cases to separate these two functions; but, after what has been said, we cannot doubt that the occasional introduction of pollen from another flower must be beneficial. Pollen will, no doubt, be brought from flowers of other species; but this will not be injurious—it will have no effect whatever.

Sexuality distinct from the existence of separate generative organs:

Sexuality, and the existence of distinct generative organs, are not the same thing, and do not imply each other. The existence of separate generative organs is only a case of the "physiological division of labour," in virtue of which law every separate function in the ascending scale of organization tends to acquire a separate organ for itself. There are many cases of the action of the reproductive function through distinct reproductive organs without the sexual relation coming into play: the females of some butterflies, for instance, produce true eggs from true ovaries, which are fertile without being fertilized by the male.[1] And, on the other hand, the instance of the lower Algæ, mentioned above, shows that sexuality may exist without separate reproductive organs, or even distinction of sexes; and that it essentially consists in the union and fusion of germinal matter from two distinct sources. It consequently appears a highly probable conclusion, that sexuality, though a universal law of life, is not an ultimate one, but is to be referred to the necessity for slight changes, in order to keep up the vigour of life. Many of the lower organisms, no doubt, propagate by spontaneous division, as the simpler Algæ; others, by throwing off buds, as the Hydra; others, which are not so lowly organized, by true eggs that have not been fertilized by the male, as the butterflies just mentioned; and others are capable of fertilizing themselves by a truly sexual process, like many flowers. But it appears probable that no organic species

depends on the necessity of slight changes.

[1] Spencer's Principles of Biology, vol. ii. p. 214.

No species can live an indefinite time without sexual reproduction.

is able to go on doing so for an indefinite number of generations.[1] It appears probable that any race whatever will at last lose its vigour, and die out, if its life is not, as it were, renewed by the mixture of germinal matter from another source.

Variability promoted by slight change of conditions, and by mixture of races.

But, whatever may be the ground of the law of sexuality, there can be no doubt of the beneficial effect both of slight changes in the conditions of life, and of mixture of nearly allied though distinct races; and it is also true, that changes in the circumstances of life, and mixture of races, tend to promote variability.[2]

Variability and modifiability.

I am now speaking of spontaneous variation. This, as I have mentioned at the beginning of this chapter, is a distinct thing from functionally-produced change; and I propose to call the tendency of a race to vary spontaneously, *variability*, and its aptitude for acquiring functionally-produced changes, *modifiability*. These two properties are different; but there is, I think, a good deal of reason for believing that they are, to a great extent, found together—at least among the highest animals. The wonderful modifiability of the instinctive faculties of the dog, which has enabled him to acquire totally new instincts under domestication, must, I think, be in some way connected with the variability of his form, which has given origin to such different races as the greyhound and the terrier.

Spontaneous variation, how far connected with the laws of habit:

Spontaneous variations may be defined as those differences of offspring from parent, and of the offspring of the same parents from each other, for which no reason can be assigned. These do not come under the law of habit, in that they do not originate, in virtue of that law, by the repetition of actions; but they do come under the law of habit, in that they are instances of the variability of habit,

[1] Darwin's Origin of Species, p. 109.

[2] See Darwin's Origin of Species, p. 21. The statement that changes in the conditions of life tend to promote variability is repeated several times throughout the work, and is illustrated by the examples of various domestic animals and cultivated plants.

and also in their tendency to become hereditary, and in their greater tenacity the longer they have been inherited through successive generations.

There is this important difference between functionally-produced changes and spontaneous variations, that functionally-produced changes are necessarily produced during the lifetime of individuals, though they may be transmitted to the offspring; but spontaneous variations appear to take their rise in the act of originating a new individual. They sometimes arise in the production of a new individual without sexual generation, as in the case of plants that produce "sports" from buds; for every branch produced from a bud may in some sense be regarded as a new individual.[1] A long list could easily be given of "sporting" plants: by this term gardeners mean a single bud or offset, which suddenly assumes a new and sometimes very different character from that of the rest of the plant. Such buds can be propagated by grafting, &c., and sometimes by seed. These sports are extremely rare under nature, but far from rare under cultivation.[2] Variations, or new varieties, are, however, oftener obtained by sexual generation. There are some species—as, for instance, the potato—which have been rendered so variable by cultivation, that new varieties are produced whenever they are raised from seed. Reproduction from seed is reproduction by sexual generation; and, as I have shown, there is some degree of mixture of race in all sexual generation. This is probably to be regarded as true even of a flower that fertilizes itself; for the anthers and the pistils, though in the same flower, are distinct elements of the organism. But of course the mixture of race is greater when the pollen is brought from another flower on the same plant, and greater still when it is brought from another plant. And, as already stated, the greater the mixture of races, the greater is the probability of variation in the offspring—provided, of course, that they are races that breed freely together, and produce fertile offspring; for the tendency to variation does not

Originates only with new individuals.

"Sporting" plants.

Variations are most abundant in cases of sexual generation.

[1] See Note at end of chapter.

[2] Darwin's Origin of Species, p. 9.

wear out, but appears to increase in the first few generations. When the breeds that are crossed are very different, the variation is so great that it is nearly impossible to obtain a permanent breed of character intermediate between the two parent breeds.[1]

Intermediate breeds are difficult to obtain.

Mixture of race, which is thus a stimulus to variation, also facilitates reversion to ancestral characteristics. Thus, in all the domestic varieties of the pigeon, birds are occasionally found that have reverted to the blue colour, with black bars on the wings, and other characters of the wild rock-pigeon, from which the domestic breeds are descended; and such specimens are particularly abundant where the breeds have been mixed.[2] Sometimes, where very unlike breeds have been mixed, the offspring are neither intermediate between the parents nor irregularly variable; but some of them resemble one parent, and some the other. Something of this is very common in families of children, where some generally resemble the father's family, and some the mother's. But the most remarkable instance I know is that of the otter, or Ancon sheep, an accidental variety that appeared at one time in North America, and was preserved by the farmers, in consequence of its being unable to leap fences. It began with a single lamb; and when the otter sheep were crossed with the common kind, some of the lambs resembled the ram, and others the ewe; but no mixed breed was ever produced.

Reversion common in mixed breeds.

Otter sheep.

Variation among animals is usually gradual, being but slight in a single generation, though, under favourable circumstances, it may accumulate through successive generations. When it is considerable, as in the case of the otter sheep just mentioned, it is usually in some degree monstrous.[3] Sudden variation is much commoner among plants, as in the case of "sporting" plants. The following cases of the sudden origin of what appear to be permanent

Variation usually slow among animals: often sudden among plants.

[1] Darwin's Origin of Species, p. 21. [2] Ibid. p. 188.

[3] It is impossible to draw the line where mere variation ends and monstrosity begins. A variation of a degree that would be called a monstrosity in an animal, would be called only a "sport," or a singular variety, in a plant.

varieties of plants are mentioned on the authority of M. C. Naudin[1]:—"The first case mentioned is that of a poppy, which took on a remarkable variation in its fruit—a crown of secondary capsules being added to the normal central capsule. A field of such poppies was grown, and M. Göppert, with seed from this field, obtained still this monstrous form in great quantity. Deformities of ferns are sometimes sought after by fern-growers. They are now always obtained by taking spores [seeds] from the abnormal parts of a monstrous fern; from which spores ferns presenting the same peculiarities invariably grow. . . . The most remarkable case is that observed by Dr. Godron, of Nancy. In 1861 that botanist observed, amongst a sowing of *Datura tatula*, the fruits of which are very spinous, a single individual of which the capsule was perfectly smooth. The seeds taken from this plant all furnished plants having the character of this individual. The fifth and sixth generations are now growing without exhibiting the least tendency to revert to the spinous form. More remarkable still, when crossed with the normal *Datura tatula*, hybrids were produced, which, in the second generation, reverted to the two original types, as true hybrids do."

Poppy.

Ferns.

Datura tatula.

The last statement may be compared with what has been mentioned above, as to the impossibility of obtaining a breed intermediate between the common and the otter sheep.

Very little is known about the laws of variation. We may, however, make the following statements with confidence:—

Variation is not always going on, nor does it go on in every part of an organism at once. Many races produce hardly any variations; and, among the variable ones, some characters are more variable than others; and when a character has recently varied, it is apt to continue variable,

Only some races are variable, and some characters of those.

[1] Quoted from the *Comptes Rendus*, in the Quarterly Journal of Science, October 1867, p. 527.

having, as I have already expressed it, acquired a habit of varying. Thus, among the domestic races of animals, the most variable characters are those in which each breed differs from the other breeds of the same species; and these are characters which, having arisen by variation since the races were first domesticated, must have varied conspicuously in a time which is very short in comparison with the lifetime of a species.

Correlation of variations.

Certain variations are habitually found together, or, as Darwin expresses it, are correlated. The nature of the correlation is sometimes quite unintelligible: thus, perfectly white cats frequently have blue eyes instead of green, and are deaf.[1] But in many cases it is to be referred to the simple and intelligible law, that homologous parts tend to vary together. Thus, similar characters on the opposite sides of the body are so much a matter of course, that any exception to the law is regarded as a monstrosity —as, for instance, when the hands are of unequal length; and, in the same way, the hands and the feet, which are homologous parts, usually have similar characters. It would be very difficult to find a person with large hands and small feet, or the reverse.

Homologous parts vary together.

Mental and motor characters are more variable than formative ones.

Throughout the organic creation some classes of functions appear to be much more variable than others. Mental and motor habits are much more variable than formative ones: thus, in man, mental characters are incomparably more variable than bodily ones as between different individuals, and also more modifiable by education and circumstances. The same appears to be true of the domestic races of animals, at least of the more intelligent ones. As instances of the changeableness of purely motor functions may be mentioned the cases of the domestic hen, duck, and goose, which from disuse have nearly lost the power of flight, without the muscles of their wings being diminished in size in any proportionate degree. These are cases of functionally-changed habit. The habit from which the tumbler variety of the pigeon derives its name is a far more extraordinary case, and is certainly unique among

[1] Darwin's Origin of Species, p. 12.

flying animals: it must have originated in some spontaneous variation.

The minutest structure is the least variable.

Among formative functions it appears to be a law that the minutest structures are the least variable. Thus, the form of the leaves of any species of tree is in general tolerably constant, while the form of the entire tree is much more variable; and the form of organs appears to be much more variable than the structure of tissues. Very little is yet known on this subject. Darwin has made a vast collection of facts showing the variability of organs; but no one has yet made a similar microscopic examination of various tissues, for the purpose of ascertaining the degree and the limits of their variability. There is, however, a remarkable constancy of microscopic structure throughout the same species of organisms: thus, a small fragment of a tooth, even when in a fossil state, is often enough for the identification of a species;[1] and the same is true of shells, even when their forms are subject to considerable variation.[2] Dr. Beale makes the following striking remark on the constancy of histological characters throughout the same species, and their distinctness from those of other species:—

Organs and tissues. Teeth. Shells.

"The anatomical differences between corresponding tissues of closely allied species are often so distinct that the anatomist familiar with them could distinguish the one from the other. For example, it would be difficult to state in few words the difference between the unstriped muscular fibres of the bladder of the hyla [or tree-frog], of the common frog, and of the newt, and yet there is a recognisable difference; and corresponding differences can be demonstrated in other textures, if a comparison be carefully instituted."[3]

Muscular tissue.

Investigation needed.

The subject, however, needs systematic investigation. The variability of external form is visible to the eye in

1 Carpenter's Comparative Physiology, p. 152.

2 My friend the Rev. John Grainger, of Dublin, informs me that the *structure* of shells presents little that is characteristic of particular species, but the *sculpture*, or external markings, often enables the species to be determined from very small fragments.

3 Beale's edition of Todd and Bowman's Physiology, p. 41.

The dog and the pigeon.

many instances, especially in the races of the dog and of the pigeon, which are so unlike each other that no one, on merely seeing them, would guess that they belonged to the same species; and yet it is proved that they do belong to the same species, in both cases, by the fact that they breed freely together, and, in the case of the pigeon, by satisfactory evidence that all the domestic races have originated since the bird was first domesticated. If similar varieties exist in the microscopic characters of any species, they will not be obvious to the eye, but must be sought for.

The most constant characters in species are also the most constant in classes.

It is to be observed that those characters which are most constant and least liable to variation, as between individuals and between mere varieties of the same species, appear, as a general rule, to be also the most constant throughout whole wide classes. Thus, the structure of nerve, muscle, and bone is much more constant between species of the same order, and between orders of the same class, than is the distribution of the nerves and the form of the muscles and bones. To mention a very remarkable instance: the skeleton of a pterodactyle, which was a reptile organized for flight, has a strong resemblance in its general outline to that of a bird; but a microscopic examination of a fragment of one of its bones shows it to have the structure belonging to the bone of a reptile.[1] This law, that the characters which are most constant throughout the species are also the most constant throughout the group to which the species belongs, is, as I agree with Darwin in thinking, of great importance in explaining the origin of species. I only refer to it here as affording a strong presumption in favour of the truth of the opinion I have advanced, that the minutest structures are the least variable.

Bones of pterodactyle.

The lowest organisms are most variable.

The lowest organisms, on the whole, are the most variable. Vegetables are, on the whole, much more lowly organized than animals, and they are much more variable in form. The Algæ, which are among the lowest vegetables, are peculiarly variable; and among the Foraminifera, which are among the lowest animals, the variability

[1] Carpenter's Comparative Physiology, p. 140.

is so great, and the intermediate forms present such innumerable gradations, that it is utterly impossible to fix the species.[1]

"When any part or organ is repeated many times in the structure of the same individual, as the vertebræ in snakes and the stamens in polyandrous flowers, the number is variable; whereas the number of the same part or organ, when it occurs in lesser numbers, is constant."[2]

Parts repeated many times are variable.

Between these two laws—that low organisms are variable, and that the number of often-repeated parts is variable—there is this connexion, that multitude of similar parts is a mark of low organization. And we may assign this very obvious reason for both, that the lower the organism, the more will its form be a matter of indifference; and the greater the number of parts, the more will their exact number be a matter of indifference. The form of a sea-weed must be nearly a matter of indifference to its health and life; but any great deviation from the normal form in one of the higher animals constitutes deformity, and is destructive. And, similarly, a pair of legs more or less may make no difference to a centipede, but it is an affair of life or death to a quadruped.

Reason of these two laws.

The laws of ordinary spontaneous variation, as stated above, may be thus summed up:—

Summary.

Spontaneous variations are quite distinct from functionally-produced modifications. Spontaneous variation occurs only when a new individual comes into existence. It occurs oftener in cases of sexual than of non-sexual propagation, and is stimulated by mixture of races and by changes in the external circumstances of life.

Some races are more variable than others; and when a race has become variable, some characters are more variable than others. When a race, or a character, begins to vary, it will continue to vary for an indefinite time.

Homologous parts tend to vary together, and there are other correlations which cannot be reduced to any law.

[1] Carpenter on the Foraminifera, published by the Ray Society, 1862.

[2] Darwin's Origin of Species, p. 176.

Mental and motor characters are more variable, as well as more modifiable, than formative ones.

Among formative characters, the minutest structures are the least variable.

The lowest organisms vary most; and when there are many similar parts, their number is variable.

I believe that very little more than what I have stated is known on the subject of ordinary spontaneous variation. But, as I have mentioned at the beginning of this chapter, besides functionally-produced modifications and spontaneous variations, there is a third kind which it is difficult to class. These take place only in organisms of low type.

Third class of changes.

Crystals vary with the medium from which they are deposited.

It has been mentioned in the chapter on Crystallization, that crystals of the same species—that is to say, of the same chemical composition and the same "crystallographic elements"—often differ very much in form, according to the character of the medium from which they have crystallized. This variability is regular; that is to say, the same alteration in the medium determines the same peculiarity in the form of the crystal. Thus, "common salt crystallizing from pure water forms cubes; but if the water contains a little boracic acid, the angles of the cubes are truncated." "Carbonate of copper, crystallizing from a solution containing sulphuric acid, forms hexagonal tabular prisms; but if a little ammonia is added, the form changes to that of a long rectangular prism with secondary planes on the angles; if a little more ammonia is added, several varieties of rhombic octahedra appear."[1]

Similar variations in fungi.

Similar variations from similar causes appear to take place among many low organisms, especially among those Fungi which constitute mould. We have not what can be called direct evidence of this; but there is evidence that the forms of the inferior Fungi are extremely variable;[2] and it is scarcely possible to doubt that the various forms of Fungi which are characteristic of particular situations

[1] P. 75.

[2] "It is asserted by Fries, that out of a single species of *Thelephora* more than eight genera have been constructed by various authors." (Carpenter's Comparative Physiology, p. 214.) Compare what has been said above on the variability of the Foraminifera.

are not all really distinct species, but that the same germ will develop into different forms, according to the soil on which it falls. "Thus, no *Puccinia* but the *Puccinia rosæ* is found upon rose-bushes, and this is seen nowhere else; *Omygena exigua* is said to be never seen but on the hoof of a dead horse; and *Isaria felina* has only been observed upon the dung of cats deposited in humid and obscure situations."[1] We can scarcely believe that the air is full of the germs of distinct species of Fungi, of which one never vegetates until it falls on the hoof of a dead horse, and another till it falls on cat's dung in a damp and dark place. It is probable—indeed, in my mind, certain—that among the lower Fungi, as among crystals, the same species assumes different forms according to the medium in which the development takes place.

Variations of this kind are clearly not of the class of spontaneous variations, for the form is determined by the medium in which the development takes place. It is difficult to say whether they are functionally produced. The inferior Fungi appear to be very susceptible of functionally-produced modifications: thus, they are sometimes developed in liquids, and then they assume very much of the character of Algæ.[2] But it is difficult to see how any change of form could make one of those low Fungi which constitute mould better suited to a new habitat; and I incline to think that the variations by which the same germ of mould develops into different forms, in different situations, is rather analogous to the variations of crystalline form of which I have spoken than to any result of the laws of habit.

Functionally produced modifications in fungi.

The power of some of the lower organisms to develop into different forms in different situations is probably the

Origin of Entozoa.

[1] Carpenter's Comparative Physiology, p. 214, note.

[2] Ibid. p. 198. A remarkable instance of the change caused by removing a fungus to a new medium is mentioned in a communication from Mr. Varley to the Microscopical Society of London (Zoologist, 1850, p. 2674). After describing a fungus that often destroys the common house-fly, the report goes on :—"By immersing the fly in water, Mr. Varley found that the mode of growth of the fungus was altered, the heads being no longer produced, and the whole plant becoming long, crooked, and filamentous."

explanation of what formerly was the most perplexing question in biological science—I mean the origin of the internal parasites of animals. The germs of these, I have no doubt, have been in all cases originally introduced from without, either in the food or through the skin, and have been developed into different forms from those which they would have assumed had their development taken place elsewhere. This conjecture is almost proved by the discovery of the fact that many of these internal parasites, or Entozoa, alternate by metagenesis[1] with animal forms that inhabit the earth or the water.

Their metagenesis.

NOTE.

INDIVIDUALITY.

Individuality, difficult to define among the lower organisms.

AMONG the lower organisms, it is nearly impossible to define what an individual is. The single cell of one of the lowest Algæ can scarcely be described as other than an individual, and yet it is homologous with the cells that combine to form the filaments of *zygnema*, or the fronds of the higher Algæ. The separate *hydra* is homologous with each polypite of the compound Hydrozoa; yet the latter are united into one compound organism, in much the same way that the leaves of a tree are united. In fact, the word "individual" is scarcely applicable; the expression, "morphological unit," proposed by Herbert Spencer, is better, as we can speak of morphological units of different orders. Among the higher orders of plants, the morphological units of the first order are the cells; these, by combination, form the units of the second order, which are the leaves with their stalks; these combine into units of the third order, that is to say, into branches, or axes (understanding by this term the product of a single bud), and the branches into trees: just as the unit of organization in an army may be successively taken to be the individual soldier, the company, and the regiment.

Morphological units of different orders.

[1] Metagenesis, a parallel word to metamorphosis, and signifying that two forms produce each other alternately. Thus, to take an instance from a different class, many hydra-like forms produce medusæ, and the medusæ again produce hydra-like forms.

CHAPTER XVII.

THE PROBLEM OF THE ORIGIN OF SPECIES.

HAVING in the last two chapters considered the laws of habit and variation, we are now in a position, not indeed to solve, but to state, the question of the origin of species.

In the chapter on the Chemistry of Life, we have seen that vital properties are not a resultant from the ordinary properties of matter; and that the origin of life, as much as the origin of matter and energy, must, in all probability, be directly referred to Creative Power. But the question of the origin of the distinct species and classes of living beings is quite another question, and it may be thus stated:—

We have seen, in the chapter on Organization, that organization is not the cause, but the effect of life: vitalized matter has a tendency to produce organization. We have also seen, in the last two chapters, that the characters of species are not absolutely invariable, but that modifications may be functionally produced in the lifetime of the individual, and variations, sometimes of very perceptible magnitude, may arise spontaneously in the production of new individuals; and also that, in all probability, the germs of many of the lower organisms, if developed in a new habitat, will produce new forms. Does not all this make it probable that distinct species, and even classes, have not been separately created, but that they have been all derived by descent, with modification and variation, from one, or at most a small number, of germs—mere

Have all species been separately created, or derived from a few original germs?

minute masses of germinal matter that were once vitalized by Creative Power?[1]

I believe the latter. Where I dissent from Darwin.

I believe they have been so derived, and in this I agree with Darwin. But I must again repeat here that I am not a believer in what is usually, and quite accurately, called "Darwin's theory." According to Darwin and his disciple Herbert Spencer,[2] the laws of habit and variation are sufficient to account for the whole process of modification by which the most highly organized vegetables and animals have been derived by descent from their first vitalized but unorganized germs. I altogether differ from this: I think the process of modification proves the agency of an Intelligent Power, acting through and controlling the laws of habit and variation, just as all the vital forces act through and control the inorganic ones.

I believe in a guiding Intelligence.

But before we discuss the agency by which the modification has taken place, let us consider the proofs—which, in my opinion, are overwhelmingly strong—that the modification has taken place. Several chapters, however, will be required to state the proofs even in outline; and in this chapter I intend only to reply to some of the more obvious and important objections.

Development theory, not contrary to experience.

It is often said that any theory of the origin of species by descent from other species is contrary to experience, because all experience shows that every species produces its own kind, and not some other. This objection is not of much force. What is true within the limits of a very short experience is not necessarily true in a much longer time. Thus, languages do not, at least in general, change perceptibly in a lifetime; but we know that they change in historical time: thus, Latin has given origin to the entire group of modern Romanic languages in less than two thousand years. The outlines of continents and the heights of mountains are not perceptibly changeable in historical times; but we know that in geological time they are as fleeting as the outlines of a cloud. So, if it is proved, as it

Changes in language.

Geological changes.

1 See Note at end of chapter.

2 In calling H. Spencer a disciple of Darwin, I do not mean to disparage the great originality, or the wonderful ingenuity, of his work on Biology.

is, that organisms are in any degree susceptible of variation, that variation may become indefinite in amount, if indefinite time is granted for the variations to take place, and to be added together.

No intrinsic improbability.

I cannot admit that there is any intrinsic improbability in the derivation of the highest organisms by descent from the lowest: I think the improbability is all the other way. It would be contrary to all the analogy of nature to suppose that any of the highest works were ever produced at once and by a single creative act; but it is in accordance with all that we know of the ways of nature to suppose that species, like individuals, have been developed out of simple germs. When we know that every individual organism, vegetable and animal, has been developed out of a simple structureless germ, and that there is no test, chemical or microscopic, by which the germ of one organism can be distinguished from that of another, no matter how unlike may be their mature forms; and when we know that every organic species must have had an origin, is it not most natural to believe that the origin of the species has been parallel to that of the individual? The reason why the theory of the origin of species by development is so often regarded as improbable, and as having at least a strong presumption against it, is chiefly, I believe, that it has not yet had time to become familiar. It was impossible that the development theory could be entertained at all until the very great antiquity of the earth was known; for, so long as it was believed that the order of nature was only coeval with human history, it was a necessary inference that the organic creation came into existence all at once, at the beginning of things. And it was impossible that the development theory could be argued on a right basis until it was proved that every individual is developed from a perfectly simple and unorganized germ, and until the old notion that the germ was a folded-up miniature of the perfect form was disproved.

Analogy of individual development.

Subject not yet familiar.

Separation of species by mutual sterility,

A really scientific objection to the development theory is the general fact that the union of distinct species will not produce offspring, or at least not fertile offspring; and it

has been a very generally received opinion that this criterion of distinction between species is absolute; that the distinction of species thus made and thus marked is a perfectly impassable barrier; and that, consequently, not only the first origin of life, but also the origin of every distinct species, needed a distinct act of Creative Power. In my opinion, however, Darwin has fully answered this objection by the great mass of facts brought together on this subject in the chapter on Hybridism, in his great work on the "Origin of Species." As that work is very well known and very readable, I will only state his conclusions in the barest outline; some of them have been stated already in the last chapter, but I will repeat them here.

It is true that similar organisms produce offspring together, and that unlike organisms will not produce offspring together. But it is not true that this distinction is rigid and absolute; on the contrary, it admits of gradation. Between perfect mutual fertility and perfect mutual sterility there are an indefinite number of gradations. Sometimes forms that are regarded as distinct species are perfectly fertile with each other, taking the production of the average number of seeds as the test of perfect fertility; sometimes forms that are regarded as only varieties of the same species are not perfectly fertile with each other. The fertility of different varieties and species with each other admits of various degrees, as estimated by the number of seeds produced. Sometimes hybrids are perfectly normal organisms; sometimes they are healthy, but infertile; sometimes they are weak, and perish early.

not absolute.

Reason of mutual sterility unknown.

It is important to observe that we do not know on what the mutual sterility of distinct species depends. It is certainly not on mere visible unlikeness: the various domestic breeds of pigeons are all perfectly fertile together, and yet they are more unlike in external appearance than many animals are to each other which are universally classed as distinct species, and most probably are not fertile together.[1]

[1] I say *most probably*, because the fact is very difficult to ascertain, as few animals breed freely in confinement. The case of the mule between the horse and the ass, however, is an important one on this subject;

The same is true of the various breeds of the dog: no one, merely by seeing them, would think that a greyhound and a terrier were of the same species. It is quite possible—though I only offer this as a suggestion for which it may never be possible to find proof—that mutual sterility depends on the length of time that has elapsed since the two stocks separated. The various races of pigeons have all been produced under domestication, and consequently during the historical period; but the origin of wild races may go back into geological time: so that, although the most unlike races of pigeons are more visibly unlike than the horse and the ass, the stocks of the horse and the ass may have diverged from each other hundreds of thousands of years before the stocks of the various races of pigeons began to diverge; and this may be the sole reason why all breeds of pigeons are mutually fertile, while the horse and the ass are not perfectly so.

Suggestion on the subject.

Another very obvious objection to the development theory is, that if species have been formed by slow transition, by descent, from one form to another, we ought to find innumerable transitional forms; but instead of finding these, we find that each species is quite distinct.

Transitional forms,

This is partly answered by the statement that in very many cases each species is *not* quite distinct, and that we *do* find a great variety of intermediate forms; so that—what appears a strange paradox and yet is true—it often happens that the more thoroughly a genus is known, the more difficult it is to determine which of its members are species and which only varieties.[1] But this answer is utterly insufficient. If species have been formed by slow transition, only a very small proportion of all the forms that must have existed are now living.

often still in existence,

but mostly lost.

But why do we not find their remains entombed among the rocks?

To this objection Darwin has, I think, given a conclusive

it is well known to be healthy, but not fertile. With cultivated plants experiments of this kind are in general easy.

[1] Darwin's Origin of Species, p. 58.

Imperfection of the geological record.

reply in his chapter on "the Imperfection of the Geological Record." On this subject, as on that of Hybridism, it is only necessary for me to state his conclusions in the barest outline.

Soft-bodied animals, like the naked worms and mollusca, are not preserved at all; they perish without leaving any record of their existence. The same is mostly true of land animals, though for a different reason. It is only in the rarest cases that land animals can die under such circumstances as to be buried, and afterwards fossilized. As a rule, it is only the hard parts of aquatic organisms that will be fossilized and preserved; and when they are so preserved, the older the fossiliferous beds, the less will be the chance of their preservation to our age. "The stir of the forces whence issued the world"[1] is not quiet yet, and never has been quiet. The deposition of new strata never ceases; and it must be remembered that, as the quantity of matter in the world is unchangeable, if there is deposition going on in one place, there must be an equivalent amount of denudation somewhere else—that is to say, an equivalent amount of destruction of old strata; though we habitually forget this, because we see the deposit, and do not see the denudation.

Destruction of fossils.

Denudation.

Besides the effect of denudation in destroying old fossiliferous beds, there is the effect of metamorphism—that is to say, the chemical effect of heat. It was first pointed out, I believe, by Sir John Herschel,[2] that (granting, what is unquestionable, the theory of the earth's central heat) any deposition of strata must raise the temperature of the strata underneath, exactly in the same way that putting on a warm coat raises the temperature of the skin. Such a rise of temperature, if sufficiently great, will cause a metamorphic change in the strata so covered, and will destroy their fossils. As metamorphism from this cause, as well as from the intrusion of igneous rocks, is not an exceptional but a normal action, and as the same is true of denudation,

Metamorphism.

[1] Matthew Arnold.

[2] See his letter to Sir C. Lyell, in the Appendix to Babbage's Ninth Bridgewater Treatise. Darwin has made no use of this argument.

it follows that metamorphism and denudation—fire and water—are incessantly destroying the ancient records of creation; so that all that geologists can ever hope to recover are the latest leaves of the volume, and these in but a fragmentary state, because a large proportion are covered by the sea, and others buried inaccessibly deep.

Discovery of intermediate forms.

With all this, it remains true that many intermediate forms have been discovered; and, what is a most important fact, no class—no type of form—has been found among fossil species fundamentally unlike all living classes. As has been truly remarked, all fossil forms can be arranged either in or between living groups. To mention what is, perhaps, the most striking instance of this: till very lately, the class of birds appeared to be isolated from all others; but recent discoveries have proved—or at least all but proved—the former existence of an entire order connecting the birds with the reptiles.

Reptilian birds.

Variability of histological characters.

Another objection to the development theory is that raised by Dr. Beale, and alluded to in the last chapter; namely, that although the forms and external characters of species are variable, there is no proof that their histological or minute structural characters are so. On this subject we are as yet, I believe, quite too ignorant to base any argument, either the one way or the other. My own opinion, however, based purely on the analogy of the case, is this: that as structure *differs* between species and between classes, but differs less than form, so it will be found that structure *varies* within the limits of the same species, but varies less than form.

Having thus briefly touched on the principal arguments against the development theory, I will go on with those in its favour. I cannot as yet enter on the subject of the process by which the development of new species has been brought about, and its causes; but I will here state in outline some reasons for believing in the development theory, which are to me of great weight, though they are so far from obvious that they appear to have been unnoticed until the publication of Darwin's great work.

P 2

Species are permanent varieties.

If the development theory is true, and if all species whatever, or all the species of any wide group, are descended from the same original ancestor, then, as Darwin has expressed it, "species are only well-marked and permanent varieties;" and the species of a genus stand to each other in the same relation as do the varieties of a species. Such is shown to be the case by a great amount of evidence which Darwin has collected, and arranged in a way that could only have been done by one combining his vast knowledge of the details of natural history with his power of seizing on the essential relations of a subject. As his "Origin of Species" is a well-known and very readable book, it is only necessary to state the following facts in the barest outline.

Varieties are most numerous where species are so.

"Where many large trees grow we expect to find saplings;" and when a form has been varying much within recent geological time, so as to form many species belonging to one genus, we may expect to find that it is still varying. Such is the fact: if large genera (that is to say, genera containing many species) are compared with small ones, it will be found that, on the average, a greater number of the species of the large genera than of the small ones present varieties; and those which do present varieties, present a greater number of them. These results, of course, are not uniform, only average ones.[1] What is a fact of exactly the same order, aberrant genera (that is to say, genera that are very peculiar, and not nearly akin to any others), are nearly always small genera.[2] On the theory of development, an indefinite number of intermediate forms must have existed formerly. A genus has become aberrant by the extinction of all the species and genera that formerly connected it with other known forms; and as the same causes, whatever they are, that determine the increase or the extinction of a species or of a genus usually act nearly alike on kindred species and genera, the causes that make a genus aberrant by destroying the kindred genera will also make it poor in species by destroying many of its species. Such genera are *Ornithorhynchus* and *Lepidosiren*.

Aberrant genera are poor in species.

[1] Darwin's Origin of Species, p. 65.

[2] Ibid. p. 508.

These may be compared to trees which have been left alone by the gradual destruction of their neighbours, and have at the same time lost many of their own branches.

A different fact, pointing in the same direction, is the following:—In the chapters on Habit and Variation we have seen that if a character begins to vary, it will continue to vary for an indefinite time. It is a case of this law, that when variations have arisen under domestication, and consequently a very short time ago, geologically speaking, the part that has varied, and is characteristic of the variety, continues to be the most variable part of the organism. The varieties of the domestic pigeon are the best instance of this.[1] But what I wish to remark is, that what I have just stated of the varieties of a species is equally true of the species of a genus. When any part in one species of a genus is unlike the corresponding part in the other species, whether in size or in shape, or in any other way, the same part is also usually variable as between the different varieties, and between the different individuals of the species; or, what is saying the same thing in more concise language, specific characters are more variable than generic ones.[2] For instance, in some groups of beetles the presence or absence of wings is of no importance in classification: there are genera in which some species have wings, and others have none; and sometimes this character is variable even between individuals of the same species. This fact is what might be expected on the supposition, that species are only "well-marked and permanent varieties:" on the supposition of the separate creation of every species, it is utterly inexplicable.

Characters variable as between species are so within the species.

Wings of beetles.

Reversion to ancestral characters is closely connected with variation, and is sometimes due to the same cause; namely, mixture of races. In all the breeds of pigeons, individuals are sometimes found that have reverted to the plumage of the rock-pigeon, from which the domestic breeds are descended; but these are most numerous when two breeds have been crossed. Crossing of the breeds is also a cause of general variation.

Reversion in varieties

[1] Darwin's Origin of Species, p. 180. [2] Ibid. pp. 177, 182.

and in species.

That which is true of the varieties of the pigeon is also true of the species of the genus Equus. The zebra and other species of Equus are striped: the ass usually has stripes on the back and shoulders only, though sometimes on the legs also: the horse, in general, has no stripes at all; but horses are occasionally found with stripes on the back and shoulder, and in the Kattywar breed in India these are usual, and bars on the legs are common. The fact of these stripes being characteristic of other species of the genus, and occasionally appearing in the horse, suggests that their appearance in the horse is a case of reversion; that all the species of Equus, like all the varieties of the pigeon, are the descendants of one ancestral species, and that the appearance of these stripes is a case of reversion to its characters. What greatly strengthens this presumption is, that mixture of race between different species of Equus, as between different varieties of the pigeon, increases the tendency to the production of these characters. Bars on the legs are much more common in the mule between the horse and the ass than in either the horse or the ass.[1]

Species of Equus.

Laws of variation

We thus find this law of variation, that characters which are variable as between the species of a genus are also apt to be variable as between the varieties and between the individuals of a species. And we also find this law of reversion, that individuals are sometimes found which present what appears to be the character of the original form from which all the varieties of a species, or all the species of a genus, have been descended. I believe that these laws are true on a much wider scale,[2] and will elucidate relations between species, not only of different genera, but of different classes.

and of reversion.

The law, that those characters which are variable as between the species of a genus are also variable as between

[1] Darwin's Origin of Species, p. 191.

[2] Darwin thinks that the occasional formation of a sixth finger in man may be due to reversion to the characters of a remote ancestor near the bottom of the vertebrate scale. No living species of air-breathing vertebrate has more than five digits, but that number is exceeded in fishes and some extinct reptiles. (Darwin's Variation under Domestication, vol. ii. p. 16.)

the varieties of those species, is, I think, only a particular case of a much wider law, which may be thus stated:—*The wider a group to which any character belongs, the less is that character liable to exceptions.* Thus, for instance, jointed legs are a character of all the higher Articulata, and they are found in every species of all their classes, without a single exception.[1] Wings, on the contrary, are found only in the class of true or hexapod insects; and, though general, they are by no means constant in their class. Another instance of this kind is that of the respiratory organs in the three allied molluscan classes of Gasteropoda, Heteropoda, and Pteropoda. Most members of these classes have distinct respiratory organs; but their occurrence is not universal, as some of them respire through the general surface of the body. When they do occur, their position is very variable as between the various families. In *Firoloides Desmarestii*, a heteropod, there are none, though they occur in some nearly allied species; and in one of these, by name *Atlanta Lesuerii*, some individuals have them, and others not.[2] Another instance of the same kind is that of the extraordinary larval forms presented by some of the Echinodermata in the course of their development. This peculiar mode of development, of which I shall have to speak in a future chapter, "in each order appears to be exceptional; and in certain cases it is known to be carried to its most abnormal degree in one species, while in a closely allied species of the same genus the mode of reproduction differs but slightly from the ordinary invertebrate type. It seems highly probable that even in the same species the development and independence of the first zooid may be carried to a greater or less degree according to circumstances."[3]

Extension of the above-stated law of variation.

Wings of insects.

Branchiæ of mollusca.

Development of Echinodermata.

The other law which we have seen to be established, that varieties tend to revert to the characters of the

Extension of the

[1] Except, perhaps, among the lowest of the acari, or mites.

[2] Huxley on the Morphology of the Cephalous Mollusca (Philosophical Transactions, 1853).

[3] Dr. Wyville Thomson on the Etymology of the Echinodermata (Natural History Review, July 1863).

above-stated law of reversion. ancestor of the species, and species to the character of the ancestor of the genus, is, I believe, only a case of a principle which is true far beyond the limits of species and genera. I believe that reversion sometimes occurs to the characters of very remote ancestors indeed, from which the species in which the reversion occurs is separated, not only by many myriads of generations, but by very profound changes.

Circular and bilateral flowers. One instance of this is among flowers. It can scarcely be questioned that the normal form of flowers is circular, and that (supposing the development theory to be true) flowers of bilateral[1] forms have been derived from circular ones by descent, with modification. It is to be observed, that flowers cannot be divided into two classes according as they are circular or bilateral: all the rose tribe have circular flowers, and all the foxglove tribe have bilateral ones; but among the geraniums this character is variable within the genus—indeed, I believe, within the species. Individual flowers are sometimes found which are circular, though belonging to bilateral species. This variation is Peloria. common enough to have received a name, "peloria," and, on my view, it is a case of reversion.

Another instance of what I believe to be reversion is far Non-sexual generation more extraordinary. Non-sexual generation is usually a proof, or at least a concomitant, of comparatively low organization: it is universal among the lowest animal forms; it does not occur among the true mollusca, at least in any ordinary form;[2] but it is common among the marine in worms, worms, which are about on a par with the Gasteropodous mollusca in *grade* of organization, though very unlike them in *plan*. I shall also show reason for believing that all the

[1] *Bilateral* may sound pedantic, but I prefer it to *irregular*, which is an inaccurate expression.

[2] The only known instance of non-sexual generation among the mollusca is a very extraordinary one, which occurs in their highest class, the Cephalopoda. The male of the cuttle-fish tribe bears no resemblance to the female; it is produced by one of the arms of the female being detached and undergoing a peculiar development, which transforms it into a male animal, or at least a male organ.

higher Articulata are descended from worms; and I regard as an instance of reversion to the characteristics of worms, the fact that non-sexual generation occurs among some of the lower Crustacea, and also among some genera of winged insects. The larvæ of Aphis, and of some Diptera, produce other larvæ by non-sexual generation; and some butterflies produce fertile eggs without being fertilized by the male.

Crustacea, and insects.

Having in this chapter brought forward evidence in favour of the theory of the production of species by a process of development, I intend in the next to begin the consideration of the laws of that process.

NOTE.

In the chapter on the Laws of Habit, I have stated my belief that there is no limit to the possible extent of variation, if only a sufficient number of generations is allowed. This is contrary to the general view, which is that the possible extent of variation is rigidly confined within the limits of species. It has been generally believed till now that variation can only form varieties—as, for instance, the domestic varieties of the dog and of the pigeon have been formed by variation from their original wild stocks; but that no amount of variation, even though acting through geological time, could possibly derive two such species as the dog and the cat by descent from a single ancestor.

Is there a limit to variation? I maintain the negative, in opposition to usual belief.

This view has been maintained by a singularly able writer on Darwin's theory in the *North British Review* for June 1867, who makes the following appeal to the test of fact:—

Argument of *North British* reviewer for the affirmative.

The dog varies much in size, as in all other characters, and there are some very small breeds of dogs. But the possible smallness of the dog appears to have reached its limit; for very small dogs are prized by fanciers, who are willing to pay highly for them, so that there is an inducement to breed smaller dogs than the smallest yet bred. The method of doing so would be, of course, to select the smallest dogs to breed from, and then select the smallest of the offspring. But this is not done, and apparently cannot be done. The small breeds of dogs, though they were originally produced by variation from a much larger

Limit of smallness in dogs has been attained.

stock, have ceased to vary in the direction of smaller size. The reviewer infers from this that the dog has a specific limit as to size, beyond which it is incapable of varying.

Variation held in check by reversion.

I reply to this, that every form has a tendency to revert to ancestral forms; and the limit of smallness in the dog, or the limit of any particular variation in any species, is at the point where the tendency to further variation is balanced by the tendency to reversion. But, though the dog has at present attained a limit at which the tendency to variation in the direction of smallness is held in check, there is no proof that such a limit is so grounded in the laws of life as to be absolutely impassable. All tendencies come under the laws of habit, and consequently may wear out and disappear with mere lapse of time. If, consequently, the smallest breed of dogs now in existence were kept separate and not permitted to mix with any other for a sufficiently long time—say for a thousand years—during which time all individuals that showed any tendency to revert to the larger size of the original stock should be destroyed, it is probable that the tendency to revert to the larger size would disappear: the race might then begin again to vary in the direction of smaller size; smaller individual dogs might be produced than any now in existence; and, if selection were applied to them, they would become the parents of a race of dogs which would continually grow smaller, until the tendency to variation was once more checked by the tendency to reversion.

Tendency to revert may die out with lapse of time,

and limit to variation may recede.

The reviewer shows that he is aware of this argument, but thinks that the assumption on which it rests—namely, that mere lapse of time will obliterate the tendency to reversion—is without any proof.

Of course direct proof is out of the question. Geology gives no evidence on such subjects; history is generally silent; tradition has forgotten them; and experiment is impossible in cases where an experiment might be only beginning to yield any result at the end of a thousand years. But I think it is as certain as such a thing can be, that all tendencies come under the laws of habit, and that all unused habits and unmanifested tendencies become weaker by mere lapse of time; though I admit we can scarcely ever be certain that the tendency to reversion has altogether died out.

Reason of the possibility of this.

CHAPTER XVIII.

DISTRIBUTION.

BEFORE we go any further in discussing the problem of the origin of species, it is necessary to consider the doctrine, which is chiefly associated with the great name of Cuvier, that all the facts of organization are to be directly referred to the conditions of that existence for which the organism has been created. Cuvier's doctrine,

This brief and somewhat technical statement of the theory needs to be further explained. I have already defined organization as the adaptation of structure to function;[1] and I have stated the law of the physiological division of labour, which consists in setting apart particular tissues and organs for particular functions. Cuvier's doctrine is no more than an extension of this: it is, in truth, no mere theory, but a generalized statement of unquestionable and most important facts. He taught that every part of an organism[2] is directly and specially adapted to every other part, and all to the conditions of that existence for which it has been made; and this doctrine, so far from being in his hands a mere barren truism, enabled him, with the aid of his vast anatomical knowledge, to restore many extinct organisms, which were known only by a few fragments of bone: to restore them, I say, to the mind's eye and on paper, as an architect can restore a ruin. Thus, of organic adaptation.

[1] P. 115.

[2] So far as I am aware, Cuvier made no attempt to apply this principle to vegetables; but no one who understands the rudiments of the subject can doubt that all such general principles are applicable to animals and vegetables alike.

for instance, carnivorous teeth are necessarily united with a carnivorous stomach; extremities modified for swimming, as in the seal or whale, are necessarily united with a form of body also suited for swimming. Such as these may be called functional adaptations. Besides these are what may be called structural adaptations: as, for instance, the adaptation of the form of the bones to the pressure of the muscles upon them; or the adaptation of the forms of all the organs in a serpent's body to the elongated form of its body. Functional and structural adaptations, of course, run into each other, and cannot be rigidly separated: the forms and characters of the various parts of an organism are determined by each other, and they are all collectively determined by the nature of the animal's life. Thus, a carnivorous life determines the existence of a carnivorous organization; a herbivorous life determines the existence of a herbivorous organization: so of a terrestrial or aquatic life, and of endless other classes of modifications.

Functional and structural adaptations.

The form of each part is determined by the rest, and all by the animal's life.

This is true:

Concerning this doctrine, the question is not whether it is true; for there is no doubt whatever that every organ in an organism must be adapted to all the rest, and all to its mode of life: these truths are implied in all the facts of organization, and no fact of organization can be understood without bearing them in mind. The question is, whether Cuvier's doctrine *alone* will suffice to explain the facts of organization: whether the organization of a species can be referred to the conditions of its existence alone, or whether it is a resultant from the conditions of its existence jointly with some law, or principle, of a totally different and quite peculiar kind. Cuvier maintained the former: he always asserted that the whole organization of a species was directly referable to the conditions of its existence. But the necessity is now universally recognised of admitting a modifying principle of a distinct kind from this.

but will it explain all the facts?

We must admit a further principle.

The two laws—for I admit them to be true, though I deny that they explain everything—the law, I say, that every part of an organism has its form and character deter-

mined by those of the other parts, and the law that the form and character of the whole organism are determined by the mode of its life, are inseparable from each other. But, though logically in the closest connexion, they have bearings on two very distinct parts of biological science. The first—the law that the characters of all the parts are mutually connected and mutually determined—has special bearings on the problems of morphology; the second—the law that they are collectively determined by the mode of its life—has special bearings on the problems of distribution. If those two laws were not only true, which they are, but all-explaining, which they are not, all the facts of morphology and distribution ought to be explicable by them. The distribution and habitats of every species ought to be explicable by the relation of its organization to its mode of life; and its morphology ought to be explicable by the relation, both functional and structural, of its organs to each other. Now, is it so? These questions are, in their nature, capable of being answered by an appeal to facts. I shall consider the facts of distribution first, not as being the most important, but as being the simplest, and the easiest to make intelligible.

Bearings of Cuvier's doctrine on morphology and on distribution.

It is to be observed, that even if Cuvier's doctrine were all-explaining, it would not contradict the doctrine of the modifiability of species; it would rather give support to that doctrine; because we know, from geological evidence, that the physical circumstances of localities as to climate, vegetation, &c. are subject to vast though slow changes; and if we believe that the characters of species are determined by the external conditions of their existence, it is a reasonable inference that those characters may be modified by a change in the conditions of existence. But the strongest evidence that we have of such changes in the characters of species is afforded by facts that cannot be in any sense referred to Cuvier's principle, though they are quite consistent with it.

If Cuvier's doctrine, that the organization of an animal is determined by the conditions and mode of its life, were

not only true, but true without any other modifying cause—in other words, if organization depended on the conditions and mode of life alone—it would be almost a necessary inference, that if in any two regions the conditions of life as to climate, food, and other external circumstances are nearly similar, the organic populations of the two ought also to be nearly similar; and the degree of similarity between the organic populations of any two regions ought to be in some sort of proportion to the similarity between the conditions of life in the two. But there is no such relation—not even an approximation to it. The degree of resemblance between the organic populations of any two regions depends in scarcely any degree on the similarity of climate and other conditions, but almost entirely on their contiguity or distance, and the facility with which they may have been colonised the one from the other, or both from the same source. For instance, mountain regions, when distant from each other, though having similar climates, are not found to have similar organic populations: on the contrary, the peculiar species of each mountain region are, for the most part, nearly related to the species inhabiting the neighbouring low country, but modified, as if to suit the mountain life. The inference is obvious, and I believe true, that the mountain species are, not metaphorically, but literally kindred with those of the plain: either the one group of species has been descended from the other, or both have been descended from the same source. I will mention another special and very remarkable instance of the way in which species are distributed. The three regions of Australia, South Africa, and the southern part of South America are situated between nearly the same parallels, and have nearly the same climate (including, of course, in the word climate, moisture as well as temperature); and climate is much more important in determining the conditions of life than all other influences put together. On the other hand, the three old continents, Europe, Asia, and Africa, contain every variety of climate, from the coldest to the hottest, from the driest to the wettest. But Australia, South Africa

External circumstances do not determine distribution.

Mountain species.

and South America are separated, and probably have been so for long geological ages, by wide, impassable oceans; while the lands of Europe, Asia, and Africa are continuous, and possibly have recently been more completely continuous than they are now. Accordingly we find, if we look to the distribution of the mammalia, that there is this strong resemblance between the zoological character of Europe, Asia, Africa, and also North America, notwithstanding their vast diversities of climate, that the most conspicuous and characteristic mammalian order in them all is that of the Ungulata, or hoofed animals. In Australia, on the contrary, notwithstanding its similarity in climate to that of South Africa, there is not a single indigenous Ungulate animal: all the indigenous mammalia belong to the two orders which stand lowest in the class, and are represented respectively by the kangaroo and the ornithorhynchus.[1] The mammalia which are characteristic of the southern part of South America, again, belong to the order Edentata, which are represented by the sloth and the armadillo, and are utterly unlike either the Ungulata or the characteristic Australian orders. It belongs to this class of facts, that Madagascar, notwithstanding its almost perfect similarity of climate to the neighbouring African continent, has a totally different mammalian population, chiefly consisting of lemurs, a tribe allied to the monkeys.[2] And New Zealand has no indigenous mammalia at all, their place being occupied by a remarkable tribe of wingless birds.

Distribution of mammalia in the old continents, Australia, South America, and Madagascar. Wingless birds of New Zealand.

The facts revealed in the recent geological history of the same countries are equally remarkable and important. Concerning Madagascar we have, I believe, no information as yet about the remains of extinct animals; but in the old continents, in Australia, and in South America, the extinct mammalia of the geological periods nearest to the present were, in each region, generally of the same order,

Extinct animals of each region resemble the living ones.

[1] The so-called wild dog of Australia is no real exception, as it is a half-domestic animal with the native savages.

[2] See Dr. Sclater on the Mammals of Madagascar, Quarterly Journal of Science, April 1864.

though different in species, from those which now inhabit the same region. The same is true of the wingless birds of New Zealand. And it is a general fact in geology, that the fossil species of two strata, lying conformably one on the other, present a strong resemblance even where they are not identical. The inference is obvious, though I do not say certain, that when we thus find the same area to have been inhabited, in two successive geological periods, by similar though different species, the connexion between them is that of descent. I say that, at the present stage of the argument, I do not regard this conclusion as proved. I believe I shall give ample proof of it before I have completed this work. I must, however, mention that when I speak of the newer set of species as connected with the older by the bond of descent, I do not mean direct descent like that by which we are connected with the races of men that inhabited the British Islands a thousand years ago: I mean descent modified in a peculiar way, which I shall have to explain in another chapter.

Resemblance of species in conformable strata.

Connexion by descent,

but modified.

But it may be urged, that Cuvier's principle of the perfect adaptation of the organism to the conditions of its existence may, after all, account for the facts of both the geographical and the geological distribution of species. It may be urged that we do not really know enough on the subject of the relation of the structure and characters of any species to the conditions of its life to assert that the one cannot be determined by the other. In a great variety of cases, the connexion is obvious enough; as, for instance, in the adaptation of the monkey's hand or the woodpecker's foot to a life spent in climbing trees. But where the connexion is not obvious, we have no right to infer that it does not exist. The more we know concerning the subject of the complex relations between organisms and the conditions of their lives, the more intricate do these relations appear. Darwin has insisted on this with great force, and with all his accustomed lucidity.

I reply to this argument, that it is refuted by evidence identical in kind with the evidence of experiment. There are a great many instances of organisms being introduced

by the agency of man into countries to which they were not native, and thriving so well in their new abode that they have gained on, and partly expelled, the indigenous species. Thus, European thistles and clover have covered great part of the Pampas of Buenos Ayres, and European clover and other plants are rapidly superseding the indigenous herbage of New Zealand.[1]

Foreign species gaining on native ones.

And there is evidence which, if possible, is still more direct and conclusive. No one can doubt the purpose of the webbed feet of water-fowl; yet there are geese that inhabit dry places, and make no use of their webbed feet. Nor can any one doubt that our woodpeckers' feet are adapted to climb trees; yet there is a woodpecker inhabiting the Pampas of South America, where trees are unknown.[2] The inference is obvious, and I think certain, that the "upland geese" are a colony of geese which have abandoned an aquatic life; and that the woodpeckers of the Pampas are a colony of woodpeckers which have strayed away from their aboriginal forests, or perhaps have been expelled by the increase of some other species of animal that preyed on them. In both these cases the species have become modified in their new habitats.

Upland goose.

Ground woodpecker.

Another most significant fact is, that small islands at a distance from any continent usually contain no indigenous mammalia whatever, *except bats,* and many peculiar species of these are found on such islands. How have those species originated? The obvious answer is, that they are the descendants of bats that were once blown across the sea, and have become modified into new species in their new abodes.[3]

Bats on remote islands.

A fact which at first sight is not quite so intelligible is, that among the small number of known species of land-birds that are unable to fly, a large proportion are found on islands. Thus, the Mauritius, before it was colonized by man, was inhabited by the dodo, an enormous sluggish bird; and the neighbouring island of Rodriguez was inha-

Birds on the same, unable to fly.

The dodo.

[1] Darwin's Origin of Species, p. 242.

[2] Ibid. p. 212.

[3] Ibid. p. 469.

bited by a bird, less sluggish than the dodo, but also unable to fly, called the solitaire: these two species are stated to be allied to the pigeons.[1] But the most remarkable group in the world of such birds is that which is now becoming extinct in New Zealand. These are not allied to the pigeon, but are of the same order with the ostrich. The extinct dinornis, the largest of all birds, was of this family, which is now represented by the comparatively small apteryx. As indicated in the name of the apteryx, these birds not only are unable to fly, but are without external wings. I believe the origin of these remarkable species is to be accounted for in the same way as that of the species of bats mentioned in the last paragraph. It is to be observed that the islands to which those birds belong contain no native mammalia whatever, except, I suppose, bats. The only assignable origin of those species of birds is that they are descended from flying birds, which were blown across the ocean long ages ago, and, finding the country uninhabited, became the ancestors of birds which, having plenty to eat and few enemies, in successive generations grew to an enormous size, and lost the power of flight. As the islands are without native mammalia, they could have few if any enemies on the ground; and if there were birds of prey, these could perhaps be best eluded by keeping on the ground among the dense vegetation of those islands, and not endeavouring to use the power of flight.

The solitaire.

The dinornis.

The apteryx.

Origin of such races.

We may conclude, that although the principle of the adaptation of every organic species to its mode of life, and to the external conditions of its life, is generally true, and of great importance, yet it utterly fails to account for the facts of the geographical and geological distribution of species; while the facts of distribution give some support to the theory of the origin of species by descent with modification. Especially is this true of the facts, that geology shows the same area to have been usually inhabited during two successive geological periods by similar though different species; and that geographical zoology

Cuvier's principle will not explain the facts of distribution.

These facts support the theory of descent with modification.

[1] See "The Dodo and its Kindred," by H. E. Strickland, F.G.S.

and botany show extensive contiguous areas to be usually inhabited by similar though different species, even when the climates of the two are very unlike.

In the next chapter I intend to consider how far the facts of morphology can be referred to the principle of the adaptation of every part of an organism to all the rest.

CHAPTER XIX.

MORPHOLOGY.

IN the last chapter the question was asked, whether the truth that every organism has been specially adapted to the conditions of its life will suffice to account for all the facts of the distribution of the various species of organisms through the regions they inhabit; and we have seen that although every organism is adapted to its habitat, yet this law of adaptation will not account for the facts of distribution. We have now to consider another and a parallel question.

Functional adaptations.

We know that the form and structure of every organ in an organism is adapted to its function: thus, for instance, every carnivorous animal has carnivorous teeth. It necessarily follows from this, that the organs are all functionally adapted to each other: thus, every carnivorous animal has not only carnivorous teeth, but a carnivorous stomach, and such an organization of the muscles of the legs and jaws as enables it to seize, kill, and tear its prey. So that these three—teeth, digestive organs, and muscular organs—are each adapted to the carnivorous life, and to each other. And besides these purely functional adaptations, there are

Structural adaptations.

structural adaptations; such as—to mention what is, perhaps, the most obvious instance—the adaptation of the forms of the bones to the forms and pressures of the muscles.

Is all morphology explicable by the law of adaptation?

Now, the question we have to consider is, whether these laws of structural and functional adaptation will account for all the facts of morphology, or whether the morphology of any particular species is a resultant from

the law of adaptation, jointly with some other law of a totally different and quite peculiar kind.

Statement of that law.

The law of adaptation may be briefly stated thus:—Every organ is adapted, structurally and functionally, to all the rest; and the whole organism, and every organ in it, is adapted to its mode of life. This is true; every fact of organic morphology is consistent with it, subject to some small though remarkable exceptions, of which I shall have to speak further on: but it is not true, as we shall find, that every fact of morphology can be referred to it alone.

Crystalline and organic morphology.

Crystalline morphology and organic morphology are so remote from each other, that no analogical reasoning from the one to the other can be in the slightest degree conclusive. But such analogies may be very suggestive. We have seen that crystals of the same species are subject to great variations in form, due to chemical differences in the medium from which they have been formed; and that there is reason to believe in similar variations among the lower species of organisms, due to the soil, or medium, in which they are developed. We know that in crystals, notwithstanding the variability of form within the limits of the same species, there are definite and very peculiar formative laws, which cannot possibly depend on anything like organic functions, because crystals have no such functions; and it ought not to surprise us if there are similar formative, or morphological, laws among organisms, which, like the formative laws of crystallization, cannot be referred to any relation of form or structure to function. Especially, I think, is this true of the lowest organisms, many of which show great beauty of form, of a kind that appears to be altogether due to symmetry of growth; as (to mention the best instance that occurs to me)[1] the beautiful star-like rayed

Formative laws of crystallization independent of function.

The same probably true, in part, of organic forms.

[1] I quote the following instance of the same kind of beauty resulting from regularity, from the Duke of Argyll's "Reign of Law," pp. 199, 200: [The Diatomaceæ, a group of the lowest Algæ,] "have shells of pure silex, and these, each after its own kind, are all covered with the most elaborate ornament—striated, or fluted, or punctured, or dotted, in patterns which are mere patterns, but patterns of perfect, and sometimes of most complex

Acanthometræ.

forms of the *Acanthometræ,* which are low animal organisms not very remote from the Foraminifera. These appear to consist of nothing but structureless sarcode, with a skeleton of siliceous spicules; they are allied to the *Thalassicollidæ,* of which, perhaps, they ought to be regarded as a genus. But the *Acanthometræ* are very much more definite in form than most of the *Thalassicollidæ;* yet this definiteness of form does not appear to be accompanied by any corresponding differentiation of function between different parts—or, in other words, by any physiological division of labour; and, so far as I can see, the beautiful regularity and symmetry of their radiated forms are altogether due to unknown laws of symmetry of growth, just like the equally beautiful and somewhat similar forms of the compound six-rayed, star-shaped crystals of snow.

Correlations in all organisms not referable to adaptation.

The adaptation of structure to function is the law, and indeed the definition, of organization; and the higher we ascend in the organic scale, the more definite and complete is this adaptation. But even in the very highest forms there are homologies and correlations which cannot be regarded as simply instances of adaptation. Before stating any of these, it is necessary to explain with more definiteness what is meant by homological relations. There are homologies between different species, and there are homologies within the limits of the same species. I shall consider first those which are within the limits of the same species.

Classes of homologies.

Of such homologies there are four distinct cases:—

1. Between different parts of the same organism;
2. Between the same organism at different stages of its development;
3. Between the sexes of the same species; and
4. Between forms that mutually produce each other by metagenesis.

The first three cases occur among all organisms what-

beauty. . . . In the same drop of moisture there may be some dozen or twenty forms, each with its own distinctive pattern, yet all as constant as they are distinctive, yet having all the same habits, and without any perceptible difference of function."

ever, except those very low ones that have no distinction of parts or of sexes. The fourth occurs only among comparatively low organisms. Among the higher organisms, the different cases are perfectly distinct; but among vegetable and comparatively low animal organisms, they graduate into each other: indeed, where individuality is very indefinite, it may be said that all the four are particular cases of homology between parts of the same organism.

Homologies of the parts of a tree in flower.

To make this last statement intelligible, it is necessary to take an instance; and the most obvious and familiar instance is that of a tree in flower. The tree at once bears young buds and branches with fully developed leaves. These may be regarded either as different parts of the same organism, or as distinct organisms of the same species in different stages of development. The tree also, in most cases, bears flowers of both sexes; and if the male elements are in one set of flowers and the female in another (which is a very common arrangement), the two sets of flowers may be regarded either as different organs belonging to the same organism, or as distinct organisms of the same species, but of opposite sexes.

Metagenesis of Hydrozoa.

Metagenesis, in the usual sense of the word, seldom occurs among flowering plants, but it is common among the Hydrozoa,[1] which, though unmistakeably animal, have a very remarkable resemblance to plants, both in the way in which single individuals or "morphological units" are united into compound ones, and in the relation of the generative organs to the whole compound organism. Among some Hydrozoa the generative organs consist of flower-like expansions, which never become detached from the body of the Hydrozoon which has produced them, and which are precisely analogous to flowers. But in other cases these flower-like expansions acquire a mouth and tentacles so as to be fitted for living alone. They then break off, swim away, and in many cases grow many times larger than the stock they have left, before they mature the gene-

Flower-like organs.

[1] It is, I think, to be regretted that the unmeaning word hydrozoa has been substituted for the beautiful and most appropriate word zoophytes, or *animal plants*.

rative products. Such detached freely-swimming flowers of the Hydrozoa, as they may be called without metaphor, are known as Medusæ, or jelly-fish:[1] but it is a most important fact, to which we shall have to return again, that there are Medusæ which have not this origin. It will appear at least probable, after what has been said, that the freely-swimming Medusæ which are *detached from* some Hydrozoa are homologous with the flower-like organs that remain permanently *attached to* others: and what makes this probability a certainty is, that both have been observed in the same species. The reproductive organs in the same species have been observed in some cases to break off and swim away, while in other cases they grow, mature their products, and die like a flower, without quitting the parent stock. A clearer case could not be imagined of gradation between the production of a distinct organ, and the production of a distinct organism: for, according to any common and obvious use of words, the flower-like body is only an organ if it matures its products while in connexion with its parent organism, but is a distinct organism if it is detached; and yet the fact that the two cases occur in the same species conclusively proves that they cannot be fundamentally distinct.

Medusæ.

In what sense metagenesis occurs in flowering plants.

I have said that metagenesis does not usually occur among flowering plants. But if we are to regard, not the tree, but the product of each bud, as an individual, then metagenesis takes place in all trees whatever: the leaf-bearing branches give origin to flower-buds by non-sexual generation, and the flowers give origin by sexual generation to new leaf-bearing buds, which are developed out of their seeds.

Among the homological relations within the limits of the same species, there are many facts that cannot be accounted for by the principle of the adaptation o structures and functions to each other. To use a concise technical mode of expression; there are many *correlations* which are not *adaptations*. Thus the flower-like generative organs of the Hydrozoa are essentially

[1] It ought perhaps to be mentioned that Thalassicollidæ is *not* Greek for jelly-fish.

polypites, differing from the ordinary polypites very much as flower-buds differ from leaf-buds.[1] (The polypite is the morphological unit of the Hydrozoon, as the leaf-bud is of the tree.) And in those cases where the generative organ breaks off and swims away as a Medusa, it still continues to be essentially a polypite, though greatly modified, and as it were disguised.

Homologies of the parts of Hydrozoa:

The relation between the leaf-buds and the flower-buds of a tree is exactly the same as this. It is now universally recognised that the flower-bud does not fundamentally differ from the leaf-bud; and that the flower consists of parts which are essentially leaves, but modified to do other work than that of the leaves.[2] Thus the calyx-leaves, the petals, the stamens, and the pistils, are all homologous with the leaves and with each other. This is shown by the history of their development from the bud, and is confirmed by the fact that in monstrous or abnormal flowers they all graduate the one into the other. The best instance with which I am acquainted of correlation between leaf-bearing and flower-bearing axes—that is to say, between the products of leaf-buds and of flower-buds—is that presented in the umbelliferous order, which have somewhat feathery compound leaves, composed of small leaflets, and small flowers clustered together into those beautiful regular "umbels," from which the order has its name. This resemblance between the manner in which the leaves and the flowers are each combined is a correlation which it seems quite impossible to refer to any adaptation of structure to function. The function of the leaves is to decompose carbonic acid and water, and to form organic compounds; the function of the flowers is to mature the seed; and there is no such connexion between those two functions as to make it necessary or useful that

of flowering plants.

Umbelliferæ.

[1] This is proved, not only by their morphology, but by the fact that the detached generative organs, or Medusæ, after maturing and parting with the generative products, have been observed to root themselves and develop into common polypites. (See the Rev. Thomas Hincks on the Development of Zoophytes: Quarterly Journal of Science, July 1865, p. 416, note.)

[2] This is Goethe's well-known theory, awkwardly called the theory of the metamorphosis of plants.

the leaves and flowers should be combined in the same way. The resemblance between the form of the compound leaf and of the umbel has, I believe, nothing to do with their functions, and is comparable rather to those laws of symmetry that govern crystalline form.

Their correlations not due to adaptation.

The resemblance, or difference, between flowers of opposite sexes is, of course, of exactly the same kind as the resemblance or difference between flowers and leaf-bearing axes. Both the sets of flowers consist of modified leaves; so that, however different they may be, the difference cannot be fundamental. The difference between the sexes among all organisms that have the sexes on distinct individuals appears to be of this kind. It is often very considerable and most conspicuous, but never really fundamental. Indeed, it is a remarkable fact that the secondary sexual characters of any species are generally very variable as between individuals of the species.[1] By secondary sexual characters are meant those sexual characters which do not belong to the sexual organs. I believe it may be added that such characters usually appear comparatively late in life. Thus, among the true insects, important as are the wings for the purposes of their life, their presence or absence is not a fundamental character, as is shown by these three criteria, that they are never developed till long after the insect has left the egg; that they are sometimes present and sometimes absent in the same species;[2] and that they are frequently a sexual character, being found on the males only.

Differences of the sexes not fundamental.

Secondary sexual characters are variable.

This general law, that the differences between the two sexes of the same species are not such as to affect the fundamental characters, is what might have been expected, and it needs no special explanation. The same may be said of the general law of metamorphosis, which is, that the larva is formed on the same general type as the perfect form, but is of a lower grade of organization. The true insects are the highest of all articulated animals, and the larvæ of those insects which undergo much metamor-

Metamorphosis,

in insects,

[1] Darwin's Origin of Species, p. 184.

[2] This is the case among some beetles.

phosis resemble articulated animals of a lower organization: caterpillars resemble centipedes, and maggots resemble worms. The Batrachians (frogs, toads, and newts), which are the lowest air-breathing vertebrates, in their larva or tadpole state resemble some of the most lowly organized fishes, which are below the Batrachians in grade of organization. The crabs are the highest of the Crustacea, and their larvæ are unmistakeably crustacean, but crustacean of a lower grade. But the law that metamorphosis is accompanied by advance in grade of organization is only a general law, not a universal one. Among the Crustacea there are some remarkable exceptions to it; the largest of which, though not the only one, is that of the great order of Cirrhipedes, or Barnacles, which are decidedly crustacean, but in their mature state are metamorphosed into fixed animals covered with shells, and having so great a resemblance to the Mollusca that they were classed as such until their larval forms became known. This must be regarded as a case of retrograde metamorphosis, or metamorphosis to a lower type; for the larva, which has powers of sight and motion, is certainly a higher being than the mature animal, which has neither. Among the Echinoderms (star-fishes and sea-urchins) there are some very extraordinary larval forms, which have no resemblance whatever to the perfect form; but perhaps this exception to the usual law of metamorphosis is rather apparent than real. I shall have to speak of them in the chapter on Embryology.

Batrachians, and Crustacea.

Cirrhipedes.

Retrograde metamorphosis.

Echinoderms.

We have seen that there are three cases of unlikeness of form within the limits of the same species. These are—

1. Between the larval and the mature forms;
2. Between the sexes; and
3. Between the forms that alternately produce each other by metagenesis. Under this last head, from a physiological point of view, comes, as we have seen, the relation between the leaf-bearing and the flower-bearing axes of plants.

Resemblance between

In all these three cases, as a general rule, the differences are not fundamental: what may be called the ground-plan

the forms of the same species.

is the same, although there may be conspicuous external unlikeness, as there is between the maggot and the fly, between the winged male and the wingless female of the glow-worm, and between a flower and a leaf-bearing axis.[1]

We might expect this.

This is what might be expected. We need not seek for any special adaptation to purpose in the fundamental resemblance between forms that belong to the same species; it would rather be necessary to seek for some special purpose, if we found a fundamental difference.

There is, however, a well-known and remarkable instance, and there are probably many others of the kind, where the resemblance in external characters between the sexes is carried further than is in any way needed by the purposes of life.

Nipples in man.

I speak of the existence of nipples, which are, in fact, rudimentary organs of lactation, in the male of the human species. These have no function, and consequently their existence cannot be referred to the law of the adaptation of structure to function: it must be due to a quite independent formative law.[2]

Relations of parts of the individual. Homology of hands and feet.

The same is true of many of those relations of which I have now to speak, between homologous parts of the same individual, and even between parts which are not homologous. Thus, the hands and the feet in man are evidently homologous, not only in their relation to the rest of the skeleton, but in the number and position of the bones. The resemblance is carried much further than the law of adaptation to purpose will account for. That law will not account for the fact that there are both five fingers and five toes. If the hand needs five fingers for its uses, and no more, the foot might surely have done perfectly well with fewer than five toes.

Their tendency to vary together,

As I have mentioned in the chapter on Variation, the hands and the feet tend to vary together: thus, persons with large hands usually have

[1] I say a leaf-bearing axis, not a leaf, because the flower consists of a number of modified leaves, and consequently is homologous with an axis bearing a number of leaves, not with a single leaf.

[2] A perfectly parallel case is that of the Hibernia leucophæaria, an insect of which the male is winged, while the female is "nearly, though not entirely apterous, the rudimentary wings being distinctly visible with a good magnifier." (Mr. Inchbald, in the Zoologist, 1848, p. 2151.)

large feet, and the reverse; and they frequently present corresponding monstrosities. It seems impossible that this tendency of homologous parts to vary together can be in any way referable to the law of adaptation: I believe it has much more resemblance to the law, that the similar edges and angles of a crystal are similarly modified by the formation of secondary planes on them. In this case, as in that of the nipples, I do not say, nor do I believe, that there is anything inconsistent with the law of adaptation to purpose. I only say that there are relations which are not cases of that law, and are not to be explained by it.

like similar parts of crystals.

But still more remarkable are the parallelisms between parts which are not homologous. Thus, none but ungulate or hoofed animals have horns, though horns are not found on all the Ungulata. It cannot be that no other animals have any need for them. Horns are weapons, to be used in fighting, and would have been in the highest degree useful to carnivorous animals, had they been endowed with them. The only reason, I think, that can be suggested why ungulates alone should have horns, is a reason that does not in any way come under the law of adaptation; it is, that they have a tendency to the production of horny matter, which appears in both the horns and the hoofs. I do not say that this conjecture is proved, or capable of proof; but it is supported by the fact that, when a tissue normally exists in one part of an organism, it is sometimes abnormally produced in another part, as for instance when the muscular walls of the heart are converted into a substance resembling bone. This, of course, occurs only in disease; but the tendency of the Ungulata to produce horny matter in their hoofs may in a somewhat similar manner determine its production in their horns. But, though the law of adaptation will not, I believe, account for the existence of horns on Ungulates only, it does account for their growing on the head, and not on any other part; for it is only there they could be useful.

Only ungulate animals have horns.

Reason suggested.

But there is, again, a remarkable fact concerning the position of horns on the head, which cannot, I think, be

Position of horns.

brought under the law of adaptation. It is only Ungulates with an even number of toes on the foot—that is to say, cloven-footed animals—which have horns on each side of the head. The only Ungulate with an odd number of toes that has a horn is the rhinoceros; and, instead of a horn on each side of the head, he has one on its middle line, on the snout. This coincidence is certainly remarkable. I do not, however, lay much stress on it, because the peculiar position of the horn of the rhinoceros may be an adaptation to his muscular structure, enabling him to use his weapon to the best advantage. But it is at least equally probable that his muscular structure is adapted to the position of the horn, and that the position of the horn is a case of correlation between the head and the feet, and is no more due to any adaptation of structure to function than are the formative laws of crystallization.

Rhinoceros.

Resemblances of different parts in the same organism.

It is very generally the case that different parts of the same organism, even when not homologous, are formed in much the same way. In other words, both the tissues and the manner in which the tissues are combined into organs, are alike in the different parts of the same organism. Thus, bone is peculiar to the Vertebrata, and is found both in the spine and in the limbs; and the bones of both the spine and the limbs are covered by the muscles. In the Articulata, which in many respects form a contrast and a kind of inverted resemblance to the Vertebrata, the body is divided into segments, and the limbs also are jointed; and in both the body and the limbs the hard parts cover the muscles, instead of being covered by them: so that the type of their construction is opposite to that of similar parts in the Vertebrata. In the Mollusca there is no skeleton at all, with the single exception of the cartilaginous skull of the cuttle-fish tribe (for the shell cannot be regarded as a skeleton); the body is not segmented, and there are no jointed limbs, only soft tentacles. Yet this is not connected with any inferiority of organization, for the organs of vegetative life among the Mollusca are very highly organized; and the Cephalopoda (cuttle-fish and nautilus), which are the highest Molluscan class, stand as high in

Vertebrata.

Articulata.

Mollusca.

the animal scale as any of the Invertebrata. It belongs to the same class of facts that the stem and the arms of the Crinoids are jointed in a nearly similar way.

Crinoids.

The conclusions arrived at in this chapter may be thus summed up:—

Summary of facts.

All the facts of organic morphology are consistent with the adaptation of structure to function; but there are many of the facts which are not cases of the law of adaptation, and cannot be referred to it: such as (to mention only a few examples) the resemblance, *in a greater degree than is required by any purpose of adaptation*, between the sexes of the human species, between homologous parts like the hands and feet, and between the leaf-bearing and the flower-bearing axes of the Umbelliferæ.

Correlation and adaptation distinct.

These are what Darwin calls correlations of form. It ought not to surprise us to find this principle of correlation pervading organic morphology. The wonder would be rather if we did not find laws of the kind. But what I wish to lay emphasis on is, that correlation in organic morphology is totally distinct from adaptation to function, and is much more nearly akin to the correlations of crystalline morphology. No doubt a correlation of form may serve a purpose. For instance, the correlation, amounting to identity of form, between the external organs on both sides of the body among nearly all the Vertebrata and Articulata is much more convenient than any unsymmetrical arrangement could be. But this will not apply to the correlation between the hands and the feet. The fact that the toes are the same in number as the fingers, is, as I have endeavoured to show, a case of pure correlation, which has nothing to do with adaptation. If this appears doubtful, a proof of it, which may be almost called an experimental proof, is afforded by the fact that the hands and the feet habitually vary together, and sometimes present similar monstrosities. These facts can, I think, be only compared to the laws of crystalline morphology, that edges and angles which are similarly related to similar axes are themselves similar; and that when the normal form of the crystalline species is modi-

Crystalline and organic morphology.

fied, similar or homologous edges and angles are modified alike. This last, as has been stated in the chapter on Crystallization, is true not only of modifications that arise spontaneously in the process of crystallization, but of such modifications as are artificially produced by breaking off an edge or an angle.

In this chapter we have considered only morphological relations within the limits of the species. In the next we are to extend our gaze over a much wider horizon, and to consider the morphological relations between widely separated groups.

NOTE.

Approach to metagenesis in Vallisneria spiralis.

IT has been stated (see p. 231) that metagenesis, like that of the Hydrozoa, is rare among flowering plants. *Vallisneria spiralis*, however, a plant which inhabits running streams, presents a case somewhat similar to that described among the Hydrozoa. The female flowers float on the water, like those of a water-lily: the male flowers are matured below the surface, and when the pollen is ripe they become detached, and float on the surface, where they are carried by the current among the female ones.

CHAPTER XX.

COMPARATIVE MORPHOLOGY.

IN the last chapter we have come to a conclusion which may be thus briefly recapitulated. Although the law of the adaptation of every part of an organism to the rest, and of the whole organism to its mode of life, is true; yet there are many facts of the morphology of single species which this law will not account for, and which point rather to a principle of correlation of form, analogous to the formative law of crystallization.

Specific morphology logically comes before comparative.

As yet I have spoken only of the morphology of single species. It is obviously the logical order thus to speak of the morphology of single species before the comparative morphology of different species and classes; for, were there only one organic species in existence—whether man or the oak-tree, or any other species that has a definite form—its morphology would be an object of science; but it would be impossible to study the comparative morphology of different species and classes, without basing the study on our knowledge of the morphology of single species.

Having arrived at the above-stated conclusion with respect to the principles of what may be called specific morphology, we shall find the facts of comparative morphology support that conclusion, and lead to other kindred results.

Analogy and homology.

It is necessary at the commencement to have a clear conception of the difference between *analogical* relations and *homological* relations. Two organs are analogous which perform the same function: for instance, the wing of the

Wing of bird and of insect.

bird and the wing of the insect are analogous, because they are both organs of flight; but they are not in any way homologous, because they have no resemblance either in anatomical structure, or in position relatively to the other organs of the body, or in the mode of their development. This is perhaps the best example that could be mentioned of two organs which are analogous without being homologous. Conversely, it is possible for two organs to be homologous without being analogous: perhaps the best instance of this is that of the lungs of the air-breathing Vertebrata, which are now universally believed to be homologous with the swim-bladder of the fish. This homology is made out, partly from the fact that the lungs and the swim-bladder are similarly placed with respect to the other organs of the body; and partly from the existence of a tolerably perfect transitional series from fishes that have a swim-bladder to Batrachians (newts, frogs, &c.) that breathe by means of lungs, through the remarkable group of the Perennibranchiate Batrachians.

Lungs and swim-bladder.

Homologies of respiratory organs variable.

This instance of the homology between swim-bladder and lungs introduces us to the fact, that the homologies of the respiratory organs of animals are peculiarly variable. This is not the case among the Vertebrata, except that the lungs of the air-breathing Vertebrata are not homologous with the branchiæ of fishes. And among air-breathing tribes of animals generally, the homologies of the respiratory organs are tolerably constant for each tribe. But among the water-breathing Invertebrata, the branchiæ are singularly inconstant, both as to their existence, and, where they exist, as to their position and homologies. I do not think this fact has received the attention it deserves. I shall have to recur to it as a most important one, and of great significance in accounting for that process of modification which, as I agree with Darwin in believing, has given origin to all organic forms.

Analogies and homologies within the species.

It is to be observed that what has been said about homologies and analogies between similar organs in different species is equally true of similar organs in the same individual. For instance, the fore-legs and hind-legs of a

quadruped are plainly not only analogous but homologous; they are analogous as to function, being all of them organs of support and motion; and they are homologous in their relation to the spine, and in the number and relative position of their constituent bones. In man, the arms are as plainly homologous in the same sense with the legs, both in their relation to the spine, and in the number and relative position of their constituent bones; indeed, as remarked in the last chapter, the resemblance of the hands and feet is carried much further than is demanded by any mechanical necessity. But the arms and the legs are not analogous with respect to function—in commoner language, they do different work. This, however, is not a very good example of the kind; for every man now and then uses his arms as legs. A much better example is that of the nippers of crabs and lobsters, which, like the arms of man, are evidently homologous with the legs, and yet are not capable of being used as legs. And the jaws of the Crustacea, and of all other Articulata, are homologous with their legs. This is made tolerably evident by the fact that, unlike the jaws of the Vertebrata, they open horizontally instead of vertically.

Legs and arms of Crustacea.

Jaws of Articulata.

Thus, organs belonging to the same individual may be homologous in position and structure without being analogous in function. The converse case is that of organs which are analogous in function without being homologous. The best instance I can remember of this is that of the fins of fishes. The pectoral pair and the ventral pair are homologous with each other, and homologous with the limbs of the higher Vertebrata. The caudal fin is, of course, not homologous with the pectoral and ventral fins; but it is homologous with the tail of the higher Vertebrata. And the dorsal fin is not homologous either with any other of the fish's fins, or with any organ whatever in any other vertebrate class.[1]

Fins of fishes.

[1] I believe the only organ in any other part of the animal kingdom that resembles the dorsal fin of the fish in position, is the so-called "foot" of the gasteropodous Mollusca, which in the Heteropoda is flattened into a vertical fin. This fin in the Heteropoda is ventral, not dorsal; but the ventral side in the Mollusca and Articulata corresponds to the dorsal side in the

It cannot in the least surprise us that organs, or sets of organs, like the pectoral and ventral fins, the caudal fin, and the dorsal fin, which are in no degree homologous as to their relation to the rest of the body, should be adapted for the same work of swimming, and for that purpose have received the same structure; being all formed of skin, supported and extended on a framework of bony rays. This is only a case of that adaptation which is the purpose of organization, and which we expect to find everywhere.

Homological resemblances carried further than necessary.

But what really needs explanation is, that homological resemblances are in many cases carried much further than is needed for any adaptation to purpose. We have seen in the last chapter that this is the case within the limits of the same species; as, for instance, between the hands and the feet of the human species, and between the two sexes of the same.

Homological resemblances and adaptive differences.

It is equally true, that between different species and groups there are homological resemblances of a degree and a kind for which no law of adaptation will account, though they are wonderfully harmonized with the law of adaptation. This is most evident among the Vertebrata, the general plan of which is much more constant than that of any of the lower groups, while it is equally susceptible of adaptive modifications for all possible kinds of life. This wonderful combination and harmony between homological resemblances and adaptive differences is best seen in tracing the homologies of the skeleton.

What I mean by the combination of homological resemblances with adaptive differences may, if the expression is not of itself intelligible, be understood by comparing the hands and the feet of man, which have the strongest homological resemblance, and yet are adapted for different functions—the feet for walking, and the hands for grasping.

Vertebrata, being the side where the nervous centres are. Huxley calls the side of the body which contains the nervous centres the neural side; that which contains the circulatory centre, or heart, the hæmal side. In the Vertebrata the neural side is the back, and the hæmal side the belly: in the Mollusca and Articulata, their relative positions are reversed. (Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.)

In a precisely similar manner, organs in different species, which are plainly homologous as to their position with respect to the rest of the body, and the number and relative position of their parts, are modified to serve totally unlike purposes in life. Thus, within the boundaries of the single class of the Mammalia, the hand of the man, the fore-foot of the dog, the wing of the bat, and the paddle of the whale, are all homologous; and not only homologous in position and in general relation to the spine and the rest of the skeleton, but down to the minutest detail: every bone in one has its homologous or corresponding bone in the others, though they are all variously modified in shape and size, to suit the purposes of the various modes of life of the animals to which they belong. Thus, if we would know all that is to be known about the various forms of vertebrate skeleton, we must understand, not only the manner in which the skeleton of each species is modified in order to adapt it to its mode of life, but also the homological resemblances that underlie the adaptive modifications. To express the same by an example: if we would know all that is to be known about the man's hand and the bat's wing, we must understand the resemblance, amounting to identity, between the number and relative position of the bones of both, as well as the structural differences which adapt the hand for grasping and the wing for flight. The law of the adaptation of structure to function will not account for this homological resemblance—not only general, but in detail—between organs that are unlike in function.

Hand, foot, wing, and paddle, all homologous.

Adaptation will not account for homology.

We see the same combination of two mutually modifying principles — morphological resemblance and adaptive difference—in comparing the vertebræ of different animals. Among fishes and serpents these are distinct, and jointed the one to the other, so as to be moveable. Among Mammalia and birds, some of the vertebræ continue to be moveable, but the form of the body, and the relation of the limbs to it, make it necessary for other vertebræ to be immoveably fastened together. Even when this is the case, however, they retain their visible distinctness as vertebræ;

Vertebræ separate in the lower Vertebrata, partly united in the higher.

although the structure formed by their coalescence would be certainly as strong, and perhaps stronger, were it of a single bone, without any vestige of division into parts: at least, we know that in works of engineering it is always best, when it is practicable, to make any part where strength in a small compass is needed, out of a single piece. But even if there is no loss of strength, there cannot be any gain of it by retaining the visible distinctness of the vertebræ. This fact is consequently not explicable as a case of the adaptation of structure to function; and it is a very remarkable case of homological resemblance continued along with, and notwithstanding, adaptive difference.

How is homology to be explained?

Unity of plan is no explanation.

How are we to explain these homological relations? Shall we be satisfied with the answer, that it has pleased the Creator to lay down a plan and keep to it? This is true: generally true, though not, like the law of gravitation, an invariable truth: but it is no explanation of the facts; it is only a generalized statement of them. Perhaps they are inexplicable, though I do not think so. I should not write as I do, were I not convinced that they are capable of explanation to a very great extent: but at least let us not advance that as an explanation which is no explanation at all. To say that the wonderful homologies of the vertebrate skeleton, to which I have little more than alluded, exist *because* the Creator has laid down a plan and adhered to it, is like saying that water rises in a pump *because* nature abhors a vacuum;—perfectly true as a statement of facts, utterly unmeaning if offered as an explanation of them.

No law subject to exceptions can be ultimate.

Further, it is, I think, a true canon in the logic of science, that no law can be an ultimate one which is subject to limitations or exceptions. By an ultimate law, I mean one which is not resolvable into any other. Gravitation is such a law, and so, as I believe, are the elementary laws of Habit. But so is not the law that nature abhors a vacuum; and when it was experimentally ascertained that nature abhorred a vacuum to no greater height than about thirty-three feet, it became evident, at least to such sound thinkers as Galileo, that the abhorrence of a vacuum

could not be an ultimate law, but was one of which an explanation ought to be sought. Just so, the law of predetermined plan in morphology proves to be subject to exceptions. I will mention one very remarkable instance. Nearly all the Mammalia have seven vertebræ in the neck, whether it is as long as in the giraffe, or as short as in the whale. The only known exceptions to this are among the various species of sloth and of manati; and these two families, it is to be observed, belong to orders that have little else in common. In the manati genus, the usual number of cervical vertebræ is six: in the *Brachypus* genus of sloths, it varies from eight to ten: but in the *Cholæpus Hofmanni*, a species of sloth lately described by Professor Peters, it is only six.[1] Such an exception as this, in my opinion, goes very far to prove that the law of homology, or the law of adherence to types, is not an ultimate law, but one which is in its own nature capable of being explained by resolving it into simpler laws; even though the facts should prove to be too inaccessible, or too complex, to admit of its being so resolved by any science possible to man.

Exceptions to plan.

Cervical vertebræ of Mammalia.

Such is the relation between the law of Homology and the law of Adaptation; so wonderful is the adherence to the minutest details of a type, while at the same time it is modified so as to make it perfectly adapted to the most different purposes (as in the case of the man's hand, the dog's foot, the bat's wing, and the whale's paddle); that it seems as if an intelligent power were adapting materials given to it by an unintelligent one. And this, I believe, is no mere illustration, but the actual fact. The Intelligent Power is that creative intelligence which, as I have already stated, I believe to direct the process of organic formation. The Unintelligent Power is the power of hereditary habit. I believe in the descent of all organisms from a few germs; I am still more strongly convinced of the descent of all organisms of the same type from the same ancestor; and as the vertebrate type is a very definitely marked one, I am fully convinced of the origin of all Vertebrates from a

Intelligent and unintelligent powers.

[1] Quarterly Journal of Science, April 1865.

Homology due to common descent. Exceptions due to spontaneous variation.

single ancestor. All those homological resemblances which are evidently not due to adaptation are in my belief due to community of descent. And those changes which are not due to adaptation, such as the abnormal number of cervical vertebræ in the sloth and the manati, are, I believe, cases of spontaneous variation.

Rudimentary organs.

What is more than any other set of facts impossible to reconcile with the independent creation of every species, or indeed with any theory of the origin of species, except that of descent with modification, is the existence of rudimentary or aborted organs. To the fact of the existence of such organs I have alluded in a former chapter, as very remarkable exceptions to the general law that all structure is adapted to function. It is impossible to assign any function for such parts as the rudimentary toes of some Ungulata (hoofed animals), which appear as if they were made for no purpose except to complete the number to five, being the usual number of toes among quadrupeds; or for the rudimentary leg-bones of some serpents; or for the rudimentary wing-bones of the apteryx, a bird of New Zealand, which has no external wings. The discovery of rudimentary organs occupies a similar place in the history and in the philosophy of biology that the discovery of the general prevalence of fossils occupies in the history and philosophy of geology. The old notion that the earth was at once created as we see it would be difficult enough to reconcile with the evident marks of aqueous and igneous action during past time; but it became obviously untenable and absurd when it was discovered that the crust of the earth is full of the buried shells and bones of extinct races; for it is impossible to believe that an Intelligent Creator would create dead shells and bones; and, in my opinion, it is not less absurd to think that an Intelligent Creator would create animals with useless organs.[1]

Toes of Ungulata.

Leg-bones of serpents: wing-bones of apteryx.

Comparison of these to fossils.

[1] It has been suggested that the purpose of apparently useless parts may be similar to that of excretory organs, and may consist in disposing of useless matter. This, however, is totally inconsistent with the facts of the case. Phosphate of lime, which is the mineral constituent of bone, is not a material of which growing animals are likely to have too much. (See Darwin's Origin of Species, p. 538.)

The only real explanation ever given of their existence is, that they have been inherited from ancestors which had the same or homologous organs in a functionally active condition; that the leg-bones of serpents, for instance, are proof of their descent from animals that had legs, and the wing-bones of the apteryx are proof of its descent from a bird that had wings. The legs and wings of the ancestral forms have been lost as a result of that remarkable law in virtue of which a disused organ diminishes not only in strength but also in size.[1]

Origin of these by descent.

Thus, though the law of adaptation is generally true, yet the existence of organs which are aborted, rudimentary, and useless, shows that it is subject to exceptions, and consequently is not a universal, ultimate, and all-explaining law. And though the law of homological parallelism—or, to use the common and very appropriate expression, the law of unity of type between organisms that are externally unlike—is generally true; as in the case already mentioned of the hand of the man, the fore-foot of the quadruped, the wing of the bat, and the paddle of the whale; yet the existence of such apparently capricious deviations from the type as that of the number of the cervical vertebræ in the sloth and the manati, shows that unity of type is not an ultimate and universal law.

Exceptions to laws of adaptation and of homology.

On the view of all organisms whatever *probably*, and *certainly* all organisms between which any unity of type is discernible, being descended from the same ancestor, the law of unity of type is fully explained. It is simply a case of hereditary habit. The fact of externally unlike organs, as alluded to in the last paragraph, being formed on what is fundamentally the same plan, is due to their being inherited from the same ancestor. But what needs further explanation, is the question how types have arisen and how they have been modified; how, for instance, and by what transitional stages, an original vitalized but unorganized germ has been modified into the fish, and the fish (which, as I shall show, is the original form of

Unity of type, a result of community of descent.

Problem of origin and modification of types.

[1] Their disappearance is, however, in great part due to natural selection, of which I shall have to speak in a future chapter.

Vertebrates) into the reptile, the bird, and the mammal? Of course, most of these questions cannot be answered in detail. As already remarked, most of the transitional forms have perished without leaving a ruin behind them. But the laws of Habit are perfectly well known, and we know something, though not much, of the laws of correlation; and with the aid of these laws it is, I believe, possible so to combine and co-ordinate the facts of embryology and comparative morphology, that in some cases, though not in all, we can arrive at definite, though general, conclusions as to the stages of modification through which organic forms have passed, and as to the causes and laws which have determined the modifications.

How do we know that rudimentary organs are aborted, and not nascent?

If this chapter is read by any intelligent man unacquainted with zoology, the question may probably occur to him, by what criterion are we able to assert that the leg-bones of serpents and the wing-bones of the apteryx are proofs of descent from animals that had legs and wings? Is it not as probable a conjecture that they are remnants of the races from which the animals that have legs and wings are descended? May not all birds be descended from the apteryx tribe, and all air-breathing Vertebrates from the serpents?

Classification.

There are two answers to this question. The one is based on the facts of classification. Serpents are not on the *line of ascent* from fishes to the air-breathing Vertebrata. The transition is not through the serpents, but through the Batrachians (newts, &c.). And there is no reason for thinking that the apteryx is on or near the line of ascent from reptiles to birds. The ascent was, in all probability, through the reptilian birds, the former existence of which has been lately shown by geological evidence.

But there is another answer, even more satisfactory than this, inasmuch as it is independent of comparative morphology, and depends only on the relation of structure to function in the species. A serpent can never have given origin to an animal with legs, or an apteryx to a bird with

wings, because the rudimentary bones in question are useless: in other words, they are not at work, and therefore are incapable of improving. Such organs as these, which have become rudimentary through disuse, are said to be *aborted.* But instances may be pointed out, of organs that are in the act of acquiring a new function; these may be called *nascent* organs for their new purpose. The best instance of this that I know of, is that of the lepidosiren, an animal concerning which it is a debated point whether it ought to be classed as a fish or a Batrachian, and which has its lungs in a state that presents an evident transition from the swim-bladder of a fish to the lungs of an air-breathing Vertebrate.

Organs if useless must be aborted.

Nascent lungs in lepidosiren.

In this chapter I have endeavoured to show, that homological resemblances between organs which are unlike in form and function are explicable only on the supposition that they are proofs of a common descent. In the next, I intend to commence the attempt to explain, by means of the laws of habit and correlation, what the course of modification in certain cases has been.

CHAPTER XXI.

EMBRYOLOGY.

Development is from simple germs.

IN the chapter on Organic Development it has been stated that all development is from the simple to the complex. Every organism is developed from a simple structureless germ, and the germs and germinal matter of all organisms are in appearance exactly alike; there is no test, chemical or microscopic, by which the germ, or small mass of germinal matter, that is capable of developing into the highest Vertebrate can be distinguished from that which is capable of developing into a worm. Consequently, if it were possible to watch the development of a Vertebrate and of a worm, or of any other widely separated species of organisms, we should first see them perfectly similar, and afterwards see them becoming gradually more and more unlike, until their development was completed.

Species become unlike as their germs develop.

Development is differentiation.

It has also been stated that development essentially consists in differentiation; that is to say, the process of development consists in the increasing unlikeness of tissues from each other, and the increasing separation of organs. When development is watched under the microscope (which can be done with many of those comparatively low animals that have bodies composed of transparent tissues, and with the eggs of fishes and frogs), the original structureless and homogeneous germ is seen to transform itself into different organs and tissues, each occupying its own part of the body of the developing organism.

From the truth that development consists in differentiation, it follows that the greatest differentiation is the highest development. Those organic species are the most

highly developed in which differentiation, that is to say the distinctness of the different organs and tissues, has been carried furthest; and those species are the lowest, or least developed, in which the original homogeneous germ has undergone the least differentiation, and remains most nearly in the original state. Consequently the undeveloped embryos of the higher forms bear some degree of resemblance to the mature states of the lower ones. That is to say, an organism which has just begun a course of what is destined to be very high development, has some resemblance to one which has completed a much lower course of development. This is a very general law, and it is, in a great variety of cases, carried out into a degree of detail that we could not have expected to find.

Embryos of higher forms resemble lower forms.

The germs of those organisms which have any decided structure do not at once begin to develop into the structure which they are ultimately to attain. The germ at first acquires a simple cellular structure, and grows by the multiplication of its cells.[1] In this condition it resembles the mature states of the Protozoa and Protophyta (the simplest animals and plants, without any distinction of tissues except that of inside and outside of cell); and this cellular mass is afterwards transformed into the organs of the developing organism. Thus the process of development is seldom or never perfectly direct; that is to say, the germ does not at once begin to transform itself into the organism that is to be. In some groups it is much more direct than in others; and, on the whole, the lower the organization the more nearly direct is the development: but this rule is subject to so many modifications and exceptions (due, as I believe, to causes that I shall endeavour to set forth at the end of this chapter), that it cannot be stated as even an average or general truth. Among the lower aquatic Invertebrata generally, the germinal mass early loses its cellular structure (if indeed it ever possessed

Development is indirect in most cases.

Generally most nearly direct in lowest groups.

Process among the lower Invertebrata.

[1] Carpenter's Human Physiology, p. 4, and Comparative Physiology, p. 176. All vegetable organisms, and the higher animal ones, appear to pass through this cellular stage of development, but it is certainly not proved of the lowest animals.

it) by the fusion of the cells into a mass of homogeneous and structureless but living sarcode, which is in fact germinal matter.[1] This sarcode mass swims about by means of cilia on its surface, and appears to perceive light and to avoid obstructions ; it almost exactly resembles one of the Protozoa, or animalcules. Within the sarcode mass the organs belonging to the organism at its next stage of development are gradually formed ; and when they are complete and ready for action, the sarcode is either gradually absorbed, which is the most usual case, or else cast off in mass.[2] This mode of development is indirect ; the Echinoderms, and the marine Mollusca and lower Annulosa, begin their life in the likeness of Protozoa, before they begin to transform themselves into their mature forms.[3]

They begin in the form of Protozoa.

The fact stated above, that the germs of the higher forms resemble the mature states of the lower ones, necessarily follows from the fact that the higher and the lower forms alike are differentiated out of perfectly simple germs, the higher ones being the most differentiated ; and these truths hold good in direct and indirect development alike. But more than this is true in indirect development. In the case of the aquatic Invertebrata just described, development begins and makes some progress on a plan of low organic type ; this plan is not continued but changed, and development begins anew on a higher type. Such change of plan during the course of development is very common among animals. In the cases just mentioned, the first plan of development is on the type of the Protozoa, which stands, as it were, at the base of the whole animal kingdom, and from which, on the theory of the origin of species by development, all

Change of plan in development.

[1] Dr. Wyville Thomson says of the embryos of the Echinoderms (star-fish, sea-urchins, &c.) : "After impregnation of the egg, and complete segmentation of the yelk, the whole germ-mass is resolved into an oval ciliated animalcule, composed throughout, and consisting entirely, of homogeneous structureless sarcode." (Natural History Review, July 1863.) I presume the "segmentation of the yelk" is an incipient formation of cells.

[2] See note at end of chapter.

[3] Dr. Wyville Thomson, in Natural History Review, October 1864.

the rest have originated; but where the higher forms of animals are developed by a similarly indirect process, their development, when the germinal mass first begins to differentiate into tissues, begins not on the plan of a Protozoon, but on that of a lower form of the same fundamental type to which the perfect form belongs.

This remarkable fact of a change in the plan of development is well known in particular cases, under the name of metamorphosis; the most familiar instance, and one of the best, is that of the transformation of the worm into the fly, or of the caterpillar into the butterfly. But metamorphosis is not confined to such obvious cases as these; it is universal among the air-breathing Vertebrata: in most of which, however, the metamorphoses are finished before the animal leaves the egg or the womb. All winged insects undergo metamorphosis, though some undergo much greater metamorphoses than others. Some leave the egg in the six-legged form of a mature insect, only without wings; others in a many-legged form like centipedes: these are the caterpillars. Others, again, leave the egg in the form of worms, without any legs, in which state they are called maggots. Now, insects are the highest class of the Articulata, centipedes are a lower class of that great group, and worms are a still lower class of the same than centipedes; so that the larval forms of insects resemble the mature forms of those lower classes to which they are allied. The same is true of the metamorphoses of the Batrachians (frogs, newts, &c.). These are air-breathing Vertebrates, and air-breathing organisms are, in general, higher than the water-breathing forms to which they are most nearly allied; but the larvæ, or tadpoles, of the Batrachians are water-breathers, and have branchiæ which are altogether homologous with those of fishes. The resemblance of tadpoles to fishes, however, is not to mature fishes, but to young or embryonic ones; and the same is true of insect larvæ: they do not resemble mature worms or centipedes, so much as immature ones.[1] To express this law in the most general terms:

Insect metamorphosis.

Metamorphosis before birth.

Insect larvæ resemble lower forms of Articulata.

So of Batrachia.

Larvæ resemble immature low forms.

[1] Carpenter's Comparative Physiology, p. 581.

when the original shapeless germinal mass begins to assume the form of the species, it first assumes an embryonic form, which is common to all organisms that are constructed on the same general plan, whether that be vertebrate, or articulate, or any other: it afterwards assumes the definite form of its species; and the highest species, being the most differentiated, depart most widely from the common embryonic form. Thus insects, for instance, being higher than centipedes or worms, depart more widely than do centipedes or worms from the embryonic or larval form which is common to all.

If the development theory of the origin of species is true, there ought to be a perfect series of species presenting transitional forms between those lowest ones which depart least in the course of their individual development from the common embryonic form of the group, to those highest ones which depart from it most widely. Between worms and insects, most of the transitional forms appear to be lost; but between fishes and the highest Batrachians there is an almost unbroken series of intermediate forms.

Transition between water- and air-breathing Vertebrates.

This series begins with the lepidosiren, an animal which is classed by Owen as a Batrachian, but by some naturalists as a fish. The series is continued through the Perennibranchiate Batrachians, a remarkable transitional order which have two sets of respiratory organs: branchiæ like those of the fish for breathing water, and lungs like those of the higher Vertebrata for breathing air. Next in the series come the newts, toads, and frogs, which differ from the Perennibranchiates in losing their branchiæ when their development is completed, so as to become air-breathers exclusively. And lastly comes the *Salamandra atra,* or land salamander, which, like the higher Vertebrata, passes through its metamorphoses in the egg, and leaves the egg in the air-breathing form.

It is most important to observe, that there is a close parallelism between the series of specific forms in the Perennibranchiate order, and the series of forms through which each individual among the higher or exclusively

air-breathing Batrachians passes in the course of its ascending development.[1]

Branchiæ of Crustacea.

Another instance of the higher forms of a group passing through stages of development similar to the mature forms of the lower species of the same group, is afforded by the branchiæ of the higher Crustacea, which in the course of their development successively present the likeness of the branchiæ of different inferior orders of the same class.[2]

Circulation in vertebrate embryo.

But probably the most instructive, if not the most obviously interesting, of all cases of development, are those of the Vertebrata. I have spoken of the developmental changes of the respiratory system in the Batrachians; and there are facts in the development of the circulatory system of the air-breathing Vertebrata which, we can scarcely doubt, are profoundly connected with these. It is obvious, from the relation of respiration to the blood, that the position of the respiratory organs, and of at least a portion of the blood-vessels, must be determined the one by the other. The blood must flow where it will be aërated: consequently, the plan of so much of the circulation as ministers to respiration must of necessity be quite different in the air-breathing Vertebrata from what it is in fishes. But in the embryos of the air-breathing Vertebrata, the blood-vessels are at first formed on the same plan as in fishes: the blood flows towards that part of the body where the fish's branchiæ are, and flows through arteries which divide and reunite as the fish's branchial arteries do; while slits are formed between the arterial branches, like those which in many fishes admit the water into the gills, although no branchiæ are ever formed. At a later period of development the plan of the circulation, so far as it is connected with the respiratory organs, is totally changed, and the "branchial slits" on each side of the neck close up and disappear.[3] Another closely-related fact is, that bodies (the "Corpora Wolffiana") are formed in the

[1] Carpenter's Comparative Physiology, p. 706.

[2] Milne-Edwards, quoted in Carpenter's Comparative Physiology, p. 745.

[3] Carpenter's Human Physiology, p. 799.

Kidneys of same.

embryos of mammalia and of birds, which are homologous with the kidneys of fishes. Unlike the branchial arteries, these perform their function at first: they act as kidneys until, before birth, they are superseded by the permanent kidneys.[1]

Brain of human embryo.

In the organs belonging to the nervous system, there is no case whatever, I believe, of any change in the plan of development: but, notwithstanding, the first embryonic brain of the highest animals is not a miniature likeness of its mature state; on the contrary, the human brain, when it can first be distinguished, is very like that of a fish; but, in conformity with the law already mentioned, it is more like that of the embryonic fish than that of the mature one. And, as the successive stages of development in the higher Batrachians correspond to the ascending series of specific forms among the lower Batrachians, and as the successive stages of development in the branchiæ of the higher Crustacea correspond to the ascending series of forms among the lower Crustacea, so do the stages of the development of the human brain correspond to the brains of the ascending series of mammalian forms.[2] This kind of correspondence, indeed, is a general law. One of the best instances of it is the development of the spinal column of Vertebrates, which begins in all as a mere tube of gelatinous substance, and afterwards becomes segmented: presenting successively, in the course of its development among the higher Vertebrata, the likeness of different forms which are those of mature forms among the inferior orders.[3]

Development of spinal column.

Another instance may be mentioned, of what we may call physiological development, as distinguished from morphological. Red blood-corpuscles are found in the Vertebrata only, and are all but universal in their mature forms:[4] but

[1] Carpenter's Human Physiology, p. 809.

[2] For these facts about the development of the brain, see ibid. p. 823.

[3] Carpenter's Comparative Physiology, p. 178.

[4] The only known exception is the amphioxus, which is the lowest of all fishes. It ought to be mentioned that some worms have red blood, but not red blood-corpuscles: the red colour is due to some diffused colouring matter.

besides the red corpuscles there are white ones, which are similar to those found in Invertebrates. In the development of the vertebrate embryo the white corpuscles appear earlier than the red; and it is now believed that throughout life the red corpuscles continue to be formed by the metamorphosis of the white. So that we have this remarkable threefold relation between the two kinds: that the white are found in lower organic forms than the red; the white appear in the embryo before the red; and the white are transformed into the red throughout life.[1]

Blood-corpuscles, white and red: their threefold relation.

What inference are we to draw from these facts of indirect development? and especially from the resemblance which we find to be so general, in various ways, throughout the animal kingdom, between the embryo or larva of the higher form, and the mature state of the kindred lower form? How are we to interpret the facts, that the lower aquatic Invertebrata usually begin their life in the likeness of Protozoa; that the branchiæ of the higher Crustacea are at first similar to those of the lower Crustacea; that many insects leave the egg as worms; that the frog and newt have the respiratory system of fishes, and consequently their circulatory system also, before they acquire those of air-breathers; and, most surprising of all, that the embryos of the higher air-breathing Vertebrata at first develop "branchial slits" and a branchial circulation like those of fishes, with the arteries dividing as the arteries of fishes divide?

It is a good rule, in all questions of this kind, to begin by trying whether the facts are capable of being all referred to Cuvier's principle of the adaptation of every organ and every function in an organism to the rest, and of all to its mode of life. But if it is difficult to apply this principle with any precision to the morphology of organisms, it is still more difficult to apply it to their development; if it is difficult to be sure that we thoroughly understand the purpose of any peculiarity of form or structure in the organism considered simply as a living mechanism, it is quite impossible to be sure that we understand all the

Can these facts be referred to the principle of adaptation?

[1] Carpenter's Human Physiology, p. 163.

purposes for which one mode of development is better than another. We can see no purpose in indirect development; for anything the wisest of us can see, the original structureless germ of every organic species might as well have developed into its mature form by the most direct process; but we are so utterly ignorant of the conditions of the problem, and any experimental test is so completely out of the question, that it would be unwarrantable presumption in us to deny that there may possibly be as real a purpose for the process of indirect development, as there is for the process of circulation or of respiration. This, I say, may be true, but all that can be said in its favour is, that there is no evidence to disprove it: and it does not appear probable. It appears very improbable, that a change of plan while development is going on should be a necessary law of development; it appears very much more likely, that the first transitory stage of an animal's development is a record, or, as it were, a picture, of what the mature form of its remote ancestor was. I believe that the likeness of the earliest forms of the lower aquatic Invertebrata to Protozoa is a record of their descent from Protozoa; that the resemblance of the larvæ of many insects to worms is a record of the descent of insects from worms; that the resemblance of the branchiæ in the larval state of the higher Crustacea to the branchiæ of the lower Crustacea in their mature state is a record of the descent of the higher Crustacea from the lower; and that the water-breathing branchiæ of the tadpole are a record of the descent of the frog from water-breathers.

We do not know the data for an answer.

They are, more probably, records of ancestral forms.

As I have just stated it, I do not say that the argument is conclusive. I think it is comparable to the argument for the descent of all the Vertebrata from a common ancestor, grounded on the homological correspondences between their skeletons being so much closer than any community of function requires. But the argument from comparative morphology, which would have been otherwise only a strong, though unverified, presumption, is raised, as I think, into a certainty by the discovery of rudimentary and useless members; which we cannot believe to have

Useless organs, and

been independently created, and which are explicable only as records of the descent of the organisms that possess them from ancestors to which they were of use. And here, in embryology, exactly the same confirmation comes in. There are not only useless organs, but useless modes of development, such as the formation in the embryos of air-breathing Vertebrates, of "branchial slits" and branchial circulation, which afterwards disappear and never perform any function. This is an exactly parallel case to that of rudimentary organs; and some of what are strictly rudimentary organs are found in embryos, and disappear before the organism comes to its mature state. Thus the embryo of the Greenland whale has teeth, which disappear by the time it is fully grown; the calf has certain teeth before birth which are afterwards absorbed;[1] and the young of some of the naked "nudibranchiate" Mollusca have discernible shells.[2] These, like the wing-bones of the wingless apteryx, are only intelligible as records of organs which were developed in the ancestors of those species, and were of use to them. It is also a significant fact, that rudimentary organs, even when they remain through life, are relatively smaller in the mature form than in the embryo;[3] this is no doubt a case of the law that unused organs diminish in size.

Useless modes of development.

Rudimentary organs in the embryo only.

Rudimentary organs largest in the embryo.

As I have stated at the beginning of this chapter, all organisms are developed from germs which are perfectly alike; and they grow more and more unlike each other as their development proceeds. This may be called the differentiation of embryos one from the other. It is now time to state the law according to which that differentiation takes place.

Differentiation of embryos.

It is a familiar truth, that organic species are naturally arranged in groups, and these groups, again, in wider groups. Thus, for instance, the domestic fowl is one of the group of birds, and birds are a part of the wider group of Vertebrates. The law in question is, that as the deve-

Groups of groups.

[1] Darwin's Origin of Species, p. 534.

[2] Carpenter's Comparative Physiology, p. 318.

[3] Darwin's Origin of Species, p. 537.

Characters of the widest group appear first.

Von Bär's law.

lopment of any organism goes on, it acquires first the characters belonging to the widest group in which it can be classed, and afterwards acquires the characters of successively narrower and narrower groups. This is known as Von Bär's law. Stated in these general terms, it will perhaps be scarcely intelligible, but an example will make it easily understood. Were it possible to watch the development of a chicken as it actually goes on in the egg, we should see it first acquire those characters which it has in common with all other Vertebrata;[1] and it would be capable of being identified as a vertebrate embryo, before it could be known to which class of oviparous Vertebrata it belonged. It would next be seen to acquire the characters of a bird, without anything to enable us to say what kind of bird; afterwards it would acquire the characters of the gallinaceous family of birds, and after that, those of the domestic fowl; last of all, the characters that distinguish the variety or breed. And this differentiating process does not stop at birth, for young animals belonging to different breeds of the same species, or to different species of the same genus, are generally—indeed almost invariably—more nearly alike than are the mature animals.

The characters of the widest group appear first—or, what means the same, the characters that appear first are those which the species has in common with the greatest number of others; and those which appear last are the peculiar characters of the species—or, in variable species, the peculiar characters of the variety or of the individual. This is the statement of Von Bär's great and simple law.

[1] "In my possession are two little embryos in spirit, whose names I have omitted to attach, and at present I am quite unable to say to what class they belong. They may be lizards, or small birds, or very young mammalia, so complete is the similarity in the mode of formation of the head and trunk in these animals. The extremities, however, are still absent in these embryos. But even if they had existed in the earliest stage of their development, we should learn nothing; for the feet of lizards and mammals, the wings and feet of birds, no less than the hands and feet of man, all arise from the same fundamental form." (Von Bär, quoted in Darwin's Origin of Species, p. 519.)

This law stands in the closest connexion with that which we have seen to be a general law of comparative morphology: I mean that those characters which distinguish the widest groups are also the least liable to variation as between orders, genera, species, or individuals within the group. The characters which appear first in the embryo are those of the widest group, and the characters of the widest group are the least subject to variation. From these two laws it follows, by syllogistic inference, that the characters which appear the earliest during development are the least subject to variation. The reason of this is tolerably evident. "If certain organs are formed early, those which come later must obviously accommodate themselves to their predecessors; and any variations which have taken place in the latter will perturb the normal disposition of the former."[1] Thus, the first-formed parts will vary only from such causes of variation as may arise in themselves; but the later-formed ones will vary, not only from such causes as may arise within themselves, but from any cause that may produce variation in their predecessors: so that the later any part is formed, the more chances it will have of varying. Whether this explanation is satisfactory or not, a good instance of the fact is presented by the contrast between the development of the Mollusca on the one hand, and that of the Articulata and Vertebrata on the other. In the Articulata and Vertebrata, the neural side of the body, or that containing the nervous centres, is developed before the hæmal side, or that containing the circulatory centre; and throughout those two great groups the general form of the nervous system is remarkably constant. In the Mollusca, on the contrary, the hæmal side is developed first, and the neural side after it; and among them the plan of the nervous system is very much less constant.[2] The Mollusca present another remarkable instance of the same law. One of the most conspicuous and best-known molluscan characters is the very unsymmetrical form of their digestive organs, the

Characters of widest groups are least variable.

Connexion of this with Von Bär's law.

Reason.

Mollusca, Articulata, and Vertebrata.

[1] Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.

[2] Ibid.

Characters not embryonic are subject to exception.

alimentary canal being doubled back so as to bring its two extremities near each other. But this character is not constant among the Mollusca: it is not found, for instance, among the chitons; and it is also not an embryonic character—on the contrary, the molluscan embryo is symmetrical, and the unsymmetrical form is subsequently produced by the right or left side, according to the species, growing more than the other.[1]

Unsymmetrical molluscan development.

Importance of embryonic characters in classification.

The parts that appear the earliest are the most constant throughout wide groups. It is a result of this fact that the most important characters for classification are frequently those of the embryo or of the larva. It is usually said, development is the criterion of morphology; but it would, I think, be more intelligible to say that development is the criterion of classification: in other words, the history of the development of any organism is the test of its true affinities. The earliest developed characters are the fundamental ones, and true classification is classification by fundamental characters. The most remarkable instance of this is that of the Cirrhipedes, or barnacles; the position of which among animals was totally misunderstood so long as they were known in the mature state only. They were classed by Cuvier as Mollusca, which they resemble only in the possession of shells, and in other superficial characters; but now that their larval forms are found to be unmistakeably crustacean, they are classed among, or near, the Crustacea. Thus, of two crustaceans, which are at first almost alike,[2] one may end its life as a crustacean, while the other undergoes metamorphosis into the very different form of a cirrhipede. But this, though I believe it is by far the most remarkable instance of the kind, is not by any means the only one. A similar case exists among the marine worms. The *dorsibranchiata* and the *tubicolæ* are very unlike in external appearance: the former are free animals, with branchiæ in rows along the back; the latter are fixed animals, inhabiting tubular shells, with branchiæ round

Cirrhipedes:

their crustacean larvæ.

Dorsibranchiata, and *tubicolæ*.

[1] Huxley on the Morphology of the Cephalous Mollusca, Philosophical Transactions, 1853.

[2] Dr. Knox's translation of Milne-Edwards's Manual of Zoology, p. 448.

the head. In some species these are magnificently developed, and, being filled with the creature's red blood, are described as presenting the appearance of a carnation flower. Yet the young of the *tubicolæ* are almost exactly like those of the *dorsibranchiata*: their subsequent unlikeness is due to their afterwards fixing themselves, forming a shell, and developing branchiæ on the head.[1]

Reversion is sometimes the retention of embryonic characters.

In a former chapter I have stated the fact of reversion, that individuals are sometimes found which present what appears to be the character of the ancestral form from which all the species of a genus, or, it may be, all the genera of a class, are descended. In this chapter we have seen reasons for believing that the image of that ancestral form is in some degree preserved in the embryo or larva. Consequently, if development is arrested, if the embryonic characters are in some degree retained, while the organism in other respects becomes fit for mature life, there will be a reversion to ancestral characters. In fewer words, retention of embryonic characters is reversion to ancestral characters. This is beyond doubt the explanation of some cases of reversion, though I do not say that it will apply to all. The best instance I know of is that of the flatfish or flounders, which differ from nearly all other vertebrates in their unsymmetrical form. They habitually swim with one side uppermost, and both their eyes are on that side. But this is true of their mature forms only. Like the Mollusca, they are symmetrically formed when in their earliest state, and assume an unsymmetrical form in the course of their subsequent development. Young flounders swim vertically, and have both sides alike, and one eye on each side of the head, like fishes of the usual type. And fully-grown individuals are sometimes found among the various species of the tribe which continue to swim vertically, and have their two sides less unequally developed than is usual among flounders.[2] Considered in reference to

Flounders.

[1] Carpenter's Comparative Physiology, p. 369.

[2] See Dr. Wyville Thomson on the Obliquity of Flounders, Annals of Natural History, May 1865. He says of the wonderful change from the young form, in which one eye is on each side, to the mature form, in which

the species only, these are monstrosities; but considered with reference to the type of the class, I have no doubt they are cases of reversion to it.

Fundamental and adaptive characters. The case of the flounders is a good instance of the difference between *fundamental* and *adaptive* characters. Embryonic characters, as we have seen, are fundamental. On the development theory of the origin of species, they are inherited from a very remote ancestry; and to the class of fundamental characters belong those homological resemblances, mentioned in the last chapter, between organs that are unlike in external form and in function, but present a minute resemblance in structure which cannot be accounted for by the law of adaptation of structure to function: such as the parallelism of formation between the hand of the man, the fore-foot of the quadruped, the wing of the bat, and the paddle of the whale. Adaptive characters, on the contrary, are acquired later in the course of development, and consist in modifications of the fundamental ones, so as to adapt them to the peculiar mode of life of the organism: such as the peculiar modifications of the common type, which fit the hand, the foot, the wing, and the paddle, each to its special function.

Homology and analogy. Homologous parts are those which are developed in the same way, and their resemblance is consequently fundamental. When organs are analogous without being homologous, on the contrary, such as the wing of the bat and the wing of the insect, they are developed in different ways, and have no resemblance in their embryonic states. Their resemblance is acquired later, and is not fundamental, but only adaptive.

Homological resemblances are fundamental. To put the contrast in its sharpest form—when organs are homologous without being analogous, the resemblance is fundamental, and the difference is adaptive; and the resemblance is greatest at first. Such are the man's hand and the bat's wing. When organs, on the contrary, are analogous without being homologous, the resemblance is

both eyes are on the same side: "The eye changes little in *actual* position: with the growth of the fish the associated parts are, as it were, *developed past it*, producing this singular obliquity."

adaptive and the difference fundamental; and there is no resemblance at first. Such are the bat's wing and the insect's wing. And similarly, though the wing of the bat is precisely analogous with that of the bird, its homologies are much nearer to those of the hand of man.

Analogical ones are adaptive.

To return to the subject of the flounders. We have seen that their peculiar unsymmetrical form is not an embryonic character. But it is plainly an adaptive one; it is to be referred to their peculiar mode of life, requiring them to be able to swim as close to the bottom as possible; for which purpose they have acquired the habit of swimming on one side instead of vertically, and have got their forms modified to suit that habit.

Flounders.

Of course, the distinction between fundamental and adaptive characters is not an absolute distinction, but admits of gradations. It is, however, generally true that the fundamental characters are the embryonic ones; and that those characters which appear first in the course of development are the least variable as between individuals, species, genera, and classes. And if it is true, as is implied in the development theory, that the most fundamental characters are those which have been inherited from the remotest ancestry, and through the greatest number of generations, it follows that the comparative invariability of fundamental characters is a case of that law of habit, in virtue of which the habits of the longest standing are the most tenacious and the least variable.

Constancy of fundamental characters, a case of the law of habit.

We have seen that nearly allied organisms undergo a similar development; and that the characteristics of the genus appear before those of the species, and the characteristics of the wider group, generally, before those of the narrower group. These laws are subject to exceptions, some of which are very difficult to explain; as when, in some cases, characters that belong to the species appear earlier than others that belong to the genus.[1] But there is a large class of exceptions of a different kind, which,

Exceptions.

[1] Stated on the authority of Agassiz, in Spencer's Principles of Biology, vol. ii. p. 378.

when properly understood, will, I believe, be found not to disprove but to confirm the principles by which I have endeavoured to explain the laws; and at the same time to throw an important light on the origin of species.

Likeness of larval form proves affinity: but not the converse.

When two organisms are developed from similar embryonic or larval forms, we infer that they are fundamentally alike; as in the case of the Cirrhipedes, which, as mentioned above, are now regarded as closely allied to the Crustacea, not from any likeness in their mature forms, but because they are developed from larvæ which are crustacean. It is indeed an axiom, that forms which are alike in their earliest stage of development are fundamentally alike, and are to be classed together. But the converse does not hold: organisms may be really allied, and yet may be developed out of very different larval forms. No one doubts, for instance, that the true or hexapod insects constitute a perfectly natural class; that is to say, a class whereof all the members have real and decided affinities to each other. Most of them leave the egg in a worm-like form; but "in some few cases, as that of Aphis, if we look to the admirable drawings by Professor Huxley of the development of this insect, we see hardly any trace of the vermiform stage."[1] And beetles constitute a perfectly natural order, yet some beetles are much more directly developed, and undergo much less metamorphosis, than others. Quite as remarkable is the case of the land salamander, which, unlike most of the higher Batrachians, does not pass through the tadpole stage, but leaves the egg as an air-breathing animal; yet we cannot doubt its affinity with the other salamanders, which begin their life as water-breathing tadpoles. Similar facts are observed among the Crustacea. "Fritz Müller has lately made the remarkable discovery that certain shrimp-like Crustaceans, allied to Penœus, first appear under the simple nauplius form, and passing through two or more zoea stages, and through the mysis stage, finally acquire their mature structure; now in the whole enormous malacostracan class, to which these crustaceans belong, no other

Insects. Beetles. Land salamander. Crustacea.

[1] Darwin's Origin of Species, p. 523.

member is yet known to be developed under the nauplius form, though very many appear as zoeas."[1] The Nauplius resembles the larva of the Cirrhipedes; and Darwin agrees with Fritz Müller that a similar form was the ancestor of the whole crustacean class.[2] It is another most remarkable fact, that the fresh-water Crustacea pass through no metamorphosis at all; their mature forms are developed directly from the egg.[3] I shall have to speak of the probable significance of this fact further on.

Fresh-water Crustacea undergo no metamorphosis.

Supposing it to be true that the larva or embryo is a picture of what the ancestral form of the species was, these facts must be accounted for by supposing that there has been a substitution of direct development for indirect; or, in other words, that one or more stages of the process of development have been left out. I mean that, when a particular course of metamorphosis is characteristic of a class, but is not found in all the members of the class, it is most probable that those species which are developed directly without metamorphosis are descended from others which passed through the metamorphosis. Such a change is consistent with what we know of the laws of Habit. In the chapter on that subject we have seen that it is a common case for an inherited variation to appear in the offspring, not at birth, but at the same age at which it first appeared in the parent; but that it sometimes appears earlier in the offspring. Now, if it is true that the embryo is a picture of the ancestral form, and that the mature form is descended from an ancestor resembling the embryonic or larval one, it follows, to use Darwin's words, that "the adult differs from the embryo [or larva], owing to variations supervening at a not early age, and being inherited at a corresponding age."[4] But if, from some spontaneous variation, the offspring inherits and manifests the variation in question, not at the corresponding age but at birth, this will amount to leaving out the first

Direct development substituted for indirect.

Laws of habit

explaining metamorphosis,

and the loss of metamorphosis.

1 Darwin's Origin of Species, p. 523. 2 Ibid. p. 531. 3 Ibid. p. 522.

4 Ibid. p. 406. I make this quotation, not as a testimony to a fact, for this can be only matter of inference, but as showing that I agree with Darwin's opinion on this part of the question.

larval stage of development. For instance, the Batrachians are, I believe, descended from an ancestor resembling a tadpole, which, from causes that I intend to speak of in a future chapter, was transformed into an air-breathing animal;[1] and in every successive generation the same change takes place, and at about the same age at which it took place in the original ancestor. But in the land salamander the change into an air-breather is inherited, not at the corresponding age, but at birth; and thus it undergoes no metamorphosis. This account of the matter is, I think, in accordance with what we know of the laws of habit and variation, and of the facts of embryology.

Batrachians.

Land salamander.

It is desirable, whenever it is possible, to adopt Darwin's plan of reasoning from relations between varieties, the common origin of which is known, to relations between species, the common origin of which can only be inferred; and Darwin has stated an instance in which the variations that mark the several varieties of one species mostly appear some time after birth, but in one variety are very conspicuous at birth. "The young of the short-faced tumbler differs from the young of the wild rock-pigeon and of the other breeds in all its proportions, almost exactly as much as in the adult state;" while the young of the other breeds of the pigeon, even of those which are most unlike in the adult state, are very nearly alike.[2] The short-faced tumbler, in presenting from the first the peculiar characters in which it differs from the original race of pigeons, may be compared to the land salamander, which breathes air from the first; while the other varieties of pigeon, in presenting at first the character of the original race, resemble those Batrachians which commence their lives breathing water, like the fishes from which they are descended.

Young pigeons of various breeds.

Series.

To return to the subject of metamorphoses. We find in nature the following series:—

[1] I do not mean that this transformation took place in one generation. On the contrary, I believe it must have occupied countless generations, and must have passed through many specific forms, like those preserved among the Perennibranchiates.

[2] Darwin's Origin of Species, p. 526.

1. Water-breathing Vertebrates (fishes) producing their like. Fishes.

2. Water-breathing Vertebrates (tadpoles) developing into air-breathers, which again produce water-breathing tadpoles from their eggs. Batrachians.

3. Air-breathing Vertebrates (the land salamander among Batrachians and all the higher vertebrate classes) producing their like. Air-breathing Vertebrates.

I believe these three form a succession by descent in the order enumerated; and I believe all the classes of air-breathing Vertebrates have been in this way descended from fishes, of which descent their embryos still bear the marks in the "branchial slits" of their arteries. Descent of the latter from fishes.

The existence of similar series in other parts of the animal kingdom is to be explained in the same way. Thus we find this series:— Series.

1. Worms producing worms. Worms.

2. Worm-like larvæ developing into hexapod insects, which again produce worm-like larvæ from their eggs. Insects developed from worm-like larvæ.

3. Hexapod insects (as Aphis) producing hexapod insects, which after they leave the egg undergo little or no metamorphosis except the acquisition of wings. No insect, however, acquires wings until some time after it leaves the egg. Insects directly developed.

Among the higher, or malacostracan Crustacea, we find quite as remarkable a series, as follows:— Crustacean series.

1. Nauplius producing its like. This, I believe, is not known by direct evidence to exist or to have ever existed; but we may infer its former existence from the fact that "forms wonderfully distinct from each other, as the suctorial parasites, Cirrhipedes, Entomostraca, and even [a few of] the Malacostraca, appear in their first larval state under a similar nauplius form."[1] From such a Nauplius all those forms have probably been descended. Nauplius.

2. Nauplius developing into zoea, thence into mysis, and thence into the mature malacostracan form of Penœus, or a genus allied thereto, which again produces Nauplii Penœus.

[1] Darwin's Origin of Species, p. 531. Darwin agrees with Fritz Müller in drawing these inferences.

from the egg. Of course it is not probable that the development of the Nauplius into any malacostracan form was effected in less than thousands, perhaps millions, of generations.

Other Malacostraca.

3. Malacostracans pursuing the same course of development as the Penœus, except that they leave out the nauplius stage and begin as zoeas.

Fresh-water Malacostraca have lost their metamorphoses by variation.

4. Fresh-water malacostracans developing by a direct process from the egg into the mature form.

The fact of the development of the fresh-water species being direct, is very significant. The fresh-waters have, it is tolerably certain, been colonized from the sea, and not the reverse: the change from salt to fresh water, like any other change, must have acted as a stimulus to variation; and variation, among other modes of action, must have, in some cases at least, the effect of causing the young to acquire the characters of the parent at birth instead of by a subsequent metamorphosis.

Series in Hydrozoa.

I have kept the case of the Hydrozoa for the last. In it we have to speak, not of metamorphosis, but of metagenesis. In that class we find the following series:—

Hydra.

1. In the common fresh-water Hydra, the generative products are matured in organs which are mere swellings on the surface of the body.

Hydrozoa with flower-like generative organs.

2. In other members of the class the generative organs are distinct flower-like expansions. From the mere swellings of the Hydra to the flower-like organs of the campanularian and sertularian Hydrozoa, there is a regular gradation; and the same anatomical elements are discernible through all the various forms of that gradation, much in the same way that the same anatomical elements are traceable through the various forms of the vertebrate skeleton.

Generative organs becoming detached as Medusæ.

3. In the forms just mentioned, the flower-like generative organs mature their products while in connexion with their parent stem, as do the flowers of plants. But in other nearly allied forms, the flower-like organs are detached before they arrive at maturity, and swim away. They grow to an enormous size in comparison with the

stock from which they have been detached, and are known as Medusæ, or jelly-fish. From the ova which they produce, animals are developed, like the parent stem, but unlike the Medusa: and these again produce Medusæ. So that we have this metagenesis, which is perhaps the most beautiful instance of the kind in the whole animal kingdom:— Meta-genesis.

A. Parent stem, comparable to the leaf-bearing trunk of a plant, producing Medusæ by a non-sexual process similar to the formation of buds by a plant.

B. Medusa, comparable to the flower of a plant, except that it is detached; producing, by a sexual process, ova that develop into the likeness of the parent stem.

There is no fundamental distinction between the species in which the flower-like organs mature their products while still in connexion with the parent stem, and those in which they become detached in the form of Medusæ. The two ways are observed in allied species; indeed they sometimes occur in the same species.

4. An instance has been observed in the genus Lizzia, and in all probability many more such instances yet remain to be discovered, of Medusæ being directly produced by a Medusa, without any metagenesis or metamorphosis.[1] Medusa producing Medusæ directly.

This series is evidently a similar one to those which I have traced through the Batrachians, the Insects, and the Crustaceans; and it is, to my mind at least, impossible to doubt that the members of this series, as of the others, have been descended each from the member enumerated before it.[2] Parallel series.

The conclusions arrived at in this chapter may be thus summed up:— Summary.

The embryonic or larval form of a species is most probably a record of what the ancestral form was from which the species has been derived.

[1] See Dr. Allman's Report on the Reproductive System in the Hydroida (Hydrozoa), British Association Reports, Newcastle, 1863.

[2] It is perhaps unlikely that the exact species from which any decidedly unlike species is descended can be still in existence; but very similar ones may be.

Nature of metamorphosis. Metamorphosis is due to variations taking place not at an early age, and being inherited at a corresponding age in the offspring.[1]

How lost. Metamorphosis, or metagenesis, may be lost by the characters of the mature form appearing at birth instead of some time after it. This is a very probable result of spontaneous variation; but the opposite change appears impossible. That is to say, it is a very probable variation for a species that has habitually undergone a metamorphosis, to acquire its mature form by direct development, and so to lose its metamorphosis; but it appears impossible that any species which has habitually acquired its mature form by direct development, should, as a result of any variation, begin to appear first in a larval form. I deduce this from the law of habit, that an inherited character sometimes appears in the offspring at the same age as that at which it appeared in the parent; sometimes earlier, but seldom or never later.

If any one, previously unacquainted with the subject, considers and compares the facts that have been brought together in this chapter, he may very probably make some comment like this: "A plausible explanation is here

[1] This does not apply to metagenesis. But metagenesis, though a less familiar fact than metamorphosis, is not nearly so difficult to account for. Such metagenesis as that of Aphis or of Cecidomyia (a dipterous insect) consists in the generation of larvæ by the larva, and needs no special explanation: what does need explanation is the metamorphosis of the larva into the perfect form, which, in Aphis at least, always occurs at intervals of a few generations. Such metagenesis as that of the Hydrozoa consists in the reproductive organs becoming detached, which may take place as the result of a very slight variation.

In metamorphosis, form *A is transformed into* form *B* (as the caterpillar into the butterfly), and form *B produces* form *A* again. In metagenesis, form *A produces* form *B*, and form *B produces* form *A* again, as in the case of the hydra-like Hydrozoon and its Medusa. In Aphis, the two processes are complicated together. Larvæ produce larvæ for several generations, and perish without undergoing metamorphosis; but at intervals they are metamorphosed into the winged state, and a new generation of larvæ is produced from their eggs. This is classed as a case of metagenesis, because there is one form in the cycle that remains permanently unlike the other: the larva that dies without undergoing metamorphosis never becomes like the winged form.

offered of the manner in which stages of development have been dropped out, and the process of development thereby shortened. But this is no explanation of the Origin of Species. The difficulty is not to know how metamorphosis and metagenesis have been suppressed, but how they began. You tell us how the land salamander[1] has ceased to begin life as a tadpole: but how did the first salamander make the transformation from a water-breathing tadpole into an air-breather? You tell us how the Aphis has ceased to appear as a worm; but how was the first worm transformed into a hexapod insect? You tell us how the fresh-water Crustacea have ceased to leave the egg as zoeas; but what determined the first transformation of a zoea into a crayfish? You tell us how the Lizzia form of Medusa has come to produce its like without alternating with a hydra-like form; but how did the first hydra-like form begin to throw off Medusæ? Until these questions, and such as these, can be answered, the mystery is unsolved." Objection.

I admit that what I have said leaves altogether unsolved the mystery of the origin of organic forms. I intend, in a future chapter, to show how far I think that mystery is capable of solution. But I cannot admit that we know nothing in any case where we are unable to ascend to a knowledge of causes. A true and correctly generalized view of facts not only is valuable in itself, but is often the means by which it becomes possible to ascend to the knowledge of causes. The discovery of Kepler's laws is justly regarded as one of the most important contributions ever made to science, though Kepler died in ignorance of the reasons of those laws; but Kepler's discoveries prepared the way for Newton's discovery of the law of gravitation, which has explained the reason, not only of Kepler's laws, but of the apparent exceptions to them. Reply.

But before going on to the subject of the causes of these transformations, I shall endeavour to show how the development theory of the origin of species agrees with the facts of classification.

[1] *Salamandra atra*, or land-newt.

NOTE.

ANOMALIES OF DEVELOPMENT.

Metamorphosis of Sitaris.

ALTHOUGH I am convinced of the truth of the principles set forth in the foregoing chapter, I admit that there are facts of development and metamorphosis for which I am utterly unable to suggest any way of accounting. One of these is that of the Sitaris beetle, which, when hatched, has six legs like a mature insect: these afterwards become rudimentary, and it assumes the ordinary form of a worm-like larva, and is transformed into a beetle in the usual way.[1]

Development of Echinoderms.

The development of some of the Echinodermata cannot be called an exception to the ordinary laws of metamorphosis only because it lies altogether outside of them.[2] As already stated, the aquatic Invertebrata are usually developed out of a germ which is nothing but a minute mass of structureless sarcode, bearing cilia on its surface, by means of which it swims about. Dr. Thomson calls this the pseudembryo: perhaps pre-embryo would be a better word. Within it the true embryo is afterwards developed; and in most cases the external ciliated "sarcode layer" is absorbed by the developing embryo, and disappears. The peculiarity of some Echinoderms is, that the pseudembryo undergoes a development of its own, which has no morphological relation to that of the future animal. Its form varies greatly in different species. In some it is described as "vermiform;" in the sea-urchin and star-fish it appears more like the Ciliograda than any other form.[3] The difference between a larva and a

Pseudembryo.

[1] Stated on the authority of M. Fabre, in Darwin's Origin of Species, p. 530.

[2] The facts in this paragraph are taken from Dr. Wyville Thomson's papers in the Natural History Review for July 1863 and October 1864.

[3] Professor Sars, who discovered the Bipinnaria, or pseudembryo of the star-fish, before he knew what it was, thought it might be allied to the Ciliograda. The resemblance in external form of Dr. Thomson's figures of the various Echinus or Sea-urchin pseudembryos to the Ciliograda is, I think, obvious enough.

pseudembryo is, that the larva is transformed into the mature form, but the pseudembryo is not so transformed; its substance is in most cases absorbed by the growing embryo: there is thus a transformation of the substance, but this is not as the substance of a larva is transformed into that of the perfect form; it is rather as food is transformed into the substance of the organism. But the pseudembryo of the star-fish, instead of being absorbed, is cast off, and continues to live for some days. Dr. Thomson quotes Dr. Carpenter's remark, that the structures first developed in the egg of the bird hold nearly the same relation to the rudimentary chick that the pluteus (pseudembryo) bears to the incipient Echinus or Ophiura, or the Bipinnaria to the incipient star-fish.

Peculiarity of that of the star-fish.

There are also these distinctions between pseudembryos and ordinary larvæ:—In the cases now under consideration, development is *not* the criterion of morphology, nor of the true affinities of the species; on the contrary, the pseudembryonic forms are much less constant throughout the class than the mature ones; and, unlike what we find in metamorphosis and metagenesis, there is no morphological resemblance whatever between the pseudembryonic and the mature forms of the Echinodermata. A tadpole and a frog are both Vertebrates; a maggot and a fly are both annulose animals; a zoea and a crab are both Crustaceans; and a Medusa is morphologically a hydrozoon, though externally much modified; but a pluteus or a bipinnaria is not in the least like an echinoderm. For these reasons I do not think it likely, or even possible, that the ancestors of the Echinodermata are in any way represented by their present pseudembryos. I am at a loss even to guess how this extraordinary mode of development can have originated.

Pseudembryos and larvæ.

CHAPTER XXII.

CLASSIFICATION.

Classification depends on Embryology.

THE subject of classification is much more familiar than that of embryology, and, apparently, has to do with much more obvious facts. Nevertheless, classification as now understood depends on embryology; for which reason I have treated of embryology first.

What is meant by the facts of classification.

At the end of the last chapter I used an expression which to many may appear strange. I spoke of the *facts of classification.* It may be asked: "What does this expression mean? What is classification but an affair of words and names? What other merit can the best classification have, than that of being the most convenient?"

Questions of classification are real.

I have in a former chapter[1] stated my conviction, which is that of most if not all men who have given any attention and thought to the classificatory sciences, that there is not only a distinction in classification of convenient or inconvenient, but also a distinction of true or false. It is perhaps difficult to prove this to the satisfaction of any one who has not a general familiarity with the outlines of those sciences; for such a conclusion is not like a mathematically demonstrated proposition, which is necessarily assented to as soon as the reasoning is understood on which it rests; on the contrary, the general conclusions of biological science mostly depend on cumulative evidence derived from a variety of facts of various kinds, and of very different degrees of importance.

[1] See p. 117.

Before going on with the subject of this chapter, I wish to remove a possible source of confusion. I have stated that questions of classification are not mere questions of words and names, but have to do with realities. Thus the assertions that the whale is not a fish, but a mammal having the external form of a fish, and that a cirrhipede is not a molluscan, but a crustacean which has put on the form of a molluscan, are assertions not merely concerning the names which naturalists have agreed to use, but concerning the real nature and affinities of those animals. These are cases of members of one group being disguised in the likeness of another, and in such cases we know nothing unless we know the real affinities of the species under review, and consequently its true classification. But there are other questions of classification which are little more than questions of words. It is, for instance, very difficult to say where the series of fishes ends, and that of Perennibranchiate Batrachians begins; it is very difficult to say whether the lepidosiren is a fish or a Batrachian. But it is as needless as it is difficult to decide such a question. The two groups run into each other, and there is so complete a gradation of intermediate forms, that the line can scarcely be drawn between them except arbitrarily. It is scarcely a metaphor to say that the lepidosiren is a fish which we have caught in the act of acquiring lungs and transforming itself into a Batrachian. But Mammalia and fishes, or Crustacea and Mollusca, are not groups that run into each other; the whale has no tendency to become a fish, nor has the cirrhipede any tendency to become a molluscan.

Questions of classification which are merely verbal.

Position of lepidosiren.

It needs no proof that the value in classification of any character depends, not on the importance of that character to the life of the organism, but altogether on the extent to which it is so correlated with other characters as to be an index to the general nature and affinities of the organism. Thus, on the one hand, as I have mentioned already, the presence or absence of wings in some groups of beetles is very inconstant, both as between otherwise similar species and between individuals of the same species;

The value of any character in classification depends on being an index to others.

Value in classification of rudimentary organs, and of organs not connected with special habits.

while, on the other hand, organs which have become rudimentary, and therefore useless, like the nails under the skin of the manati (an aquatic mammal), are regarded by the best authorities as of importance at least equal to that of organs homologous with them, but in a state of functional perfection and activity. "It may even be given as a general rule, that the less any part of the organization is connected with special habits, the more important it becomes for classification."[1] "With plants, how remarkable it is that the organs of vegetation, on which their whole life depends, are of little signification excepting in [separating the whole vegetable kingdom into] the first main divisions; whereas the organs of reproduction, with their product the seed, are of paramount importance."[2]

The development theory explains all this.

If we believe in the theory of the origin of species by development—or, to use more accurate language, if we believe that different species have been derived from a common ancestor by descent with different modifications—all this, and much more, at once becomes intelligible. Before the "development theory" became familiar to scientific men, and while the origin of species was regarded as something inscrutable, like the origin of matter or of life, though naturalists were instinctively certain that their words had a true and important meaning when they spoke of *true* classification and of *real* affinities, yet they found it impossible to state what that meaning was, in a way that was satisfactory even to themselves. But if the development theory is true, real affinity simply means affinity of kindred by descent, and true classification is by genealogy.

Affinity means kindred; as of Cirrhipedes to Crustaceans. Groups within groups.

When we say, for instance, that the Cirrhipedes, or Barnacles, though totally unlike in form and appearance, are proved by the character of their larvæ to be closely connected with the Crustacea, what we mean is, that they are literally akin to the Crustacea, being descended from crustacean ancestors. Not only every species but every genus is descended from a single ancestor; all the genera of an order are descended from a single ancestor further back; so of all the orders of the same class, and all the

[1] Darwin's Origin of Species, p. 489. [2] Ibid. p. 490.

classes of the same great division, such as the Vertebrata. Thus far, I believe the development theory is as completely proved as any truth can be, of which we have neither direct evidence nor mathematical demonstration. More than this I do not think we are yet in a position to assert with the same confidence; but I believe that all organisms whatever are descended from a common origin. It will be seen why, on this view, so much importance in classification should be attached to organs that have become rudimentary and aborted; for they show the descent of the organism as clearly as if they were conspicuous and at work. It will also be seen why the highest importance in classification is attached to those organs which are earliest formed in the embryo, and to embryonic characters generally; for the first developed characters, as shown in the last chapter, are the least variable, and have probably varied the least throughout an indefinite number of generations. And it will be seen that although the flower and the seed-vessel in plants are not developed early, yet they are of high classificatory importance for the same reason that embryonic characters are; namely, that they are unlikely to be greatly changed by any change of an adaptive nature. Adaptation to a new habitat, for instance, or change of climate, will be much more likely to change its habit and mode of growth—to make the difference, for instance, between a tree and a herb—than to make any great change in the character of the flower.

How far the development theory is proved.

Reason of importance of rudimentary organs:

of embryonic characters:

of the flower.

The foregoing remarks will all be familiar to the student of Darwin. What follows is not absolutely original; but it has not yet, I think, been stated with the emphasis it deserves.

We suppose the following to be the *rationale* of the facts of classification:—

All living beings have a capacity for variation, which is very limited in a single generation, but (like geological change) quite unlimited if sufficient time is allowed, so that the variations of successive generations may be added

Origin of organic forms by the accumulation of variations. Divergent lines of variation. Divergence and re-divergence. Classification is genealogy.

together. All organic forms have come into existence by the accumulation of such variations, ever since they began in those first vitalized but unorganized germs from which I believe all organisms to be descended. Different forms have come into existence by the accumulation of different sets of variations along different and diverging lines of descent; and these lines ever diverge and re-diverge—that is to say, forms ever become differentiated and re-differentiated from each other—giving origin to subordinate groups. Thus the true classification, could we find it, would be a genealogical table; and the best attainable classification is that which most nearly approximates to genealogical affinities.

No re-union after divergence.

In the genealogical table of a human family, if it represents the whole of the family, and not the leading branch only, there are such diverging and re-diverging lines of descent. In the human genealogy, however, lines that have diverged may reunite by the intermarriage of cousins; and thus a new line may arise, mixing the blood, and probably combining the characters, of the two parent lines. But in the organic genealogy such unions are impossible; for organisms cannot produce offspring together after they have diverged into decidedly different forms. In our organic genealogical tree, consequently, the branches, which are classes, should never reunite after diverging.

Metamorphosis generally is progress. Exception in Cirrhipedes. Specific change also is generally progress.

Further, the facts of metamorphosis, as stated in the last chapter, go to prove that when any important change takes place it is generally towards a higher form. The frog is higher than the tadpole, the butterfly is higher than the caterpillar, and the crab is higher than the zoea; and though the cirrhipede is not higher than its nauplius-like larva, this case is exceptional. And if it is true, as I have shown reason for believing, that the ancestral forms from which the *species* of these groups have been developed resembled the larvæ from which the *individuals* are still developed, then the direction of change of species, as well as of metamorphosis of the individual, is in general, though not invariably, towards higher forms.

Thus the branches of our symbolical organic tree should *never reunite* after dividing, and should *generally ascend.* Do the facts support these *à priori* conclusions?

Groups are generally united by their lower members.

So far as the facts are known they do. It is a familiar remark to naturalists that groups are united by their lower rather than by their higher members. Were this universally true, it is obvious that the organic tree would have its branches always ascending and never reuniting. This is a subject of great importance, and I must illustrate it further. The organic tree consists of two main trunks, the vegetable and the animal. It is by the lowest members of both groups that they are brought into contact. There are many forms concerning which it is uncertain whether they are animal or vegetable; and perhaps, indeed, we make ourselves the slaves of our own words when we assume that every organism must be definitely either the one or the other. The sarcode of which the bodies of the Protozoa are composed does not appear essentially to differ from the protoplasm contained in vegetable cells; and if it is true, as I think most probable, that this community of properties indicates community of origin, the germ, or germs, from which both the vegetable and animal kingdoms have been descended, must have been neither decidedly vegetable nor decidedly animal, but capable of acquiring the properties of either.

Animal and vegetable kingdoms.

Their probable common origin.

This is perhaps the best of all the many instances which might be enumerated of the general law that groups are united by their lowest members, and separated in their higher forms. We have seen that it is nearly impossible —I am inclined to think quite impossible—to make any absolute distinction between the lowest plants and the lowest animals. But between their highest forms the distinction is not only fundamental, but is also so obvious that it cannot be mistaken. The warm-blooded Vertebrata are the highest of all animals; and, though there is no vegetable class that stands so decidedly at the head of that kingdom, we cannot be far wrong if we regard the Rosaceæ and their allies as the most highly organized

No absolute distinction between them.

Their highest forms are totally unlike.

of all vegetables. Now, there is no possibility of making any confusion between an animal and a rose-bush, or an apple-tree. Science is needed, not to inform us of the difference, but to tell us of the fundamental resemblance that all plants have to all animals.

Affinities of Algæ, Lichens, and Fungi:

The same is true of the lowest of the unmistakeably vegetable classes, Thallogens. This class consists of three orders—Algæ, Lichens, and Fungi. These in their highest genera are distinct enough, but of some of their lower genera, as Protococcus, it is nearly impossible to say of which of the three orders they are members; and, indeed, on my view, they do not necessarily belong to one order more than to another. They may belong to that simple original type out of which Algæ, Lichens, and Fungi have all been developed by differentiation.

of fishes and air-breathing Vertebrata.

The next instance I shall mention is the connexion between the fishes and the air-breathing Vertebrata. The air-breathing Vertebrata are on the whole much higher in the scale of organization than the fishes; but the Perennibranchiate Batrachians, which are the lowest of the air-breathing Vertebrata, approximate, not to the highest, but to the lowest of the fishes.

Retrograde change.

Acari.

There are, however, some exceptions to this law, which may probably be regarded as parallel cases to that of the metamorphosis of Cirrhipedes, in which, as we have seen, the change is retrograde—that is to say, from a higher to a lower form. One of the most remarkable instances of this kind that I know of is that of the Acari, or mites, which are the lowest members of a class which I believe to be descended from worms, and yet do not, at least normally,[1] present the slightest approximation to the worms. This subject must be explained in some detail.

[1] I say "*at least normally,*" because there are instances of Acari presenting a form which may be due to reversion to their ancestral worm-character. "Mr. Charles Robertson, Demonstrator of Anatomy in the University of Oxford, has lately described a form of Acarus found inside pigeons, chiefly among the connective tissue of the skin, the large veins near the heart, and on the surface of the pericardium. In some respects

Those classes of animals whereof the body is composed of a succession of rings from head to tail are called the Annulosa. The annulose type is a very well-marked natural type. As in other groups, the lower limit of the Annulosa is somewhat difficult to trace, in consequence of the affinities of its lower classes being less definite than those of the higher ones; but in its higher classes, the annulose type is as well-marked a one as the vertebrate. The annulose structure is best seen in the Annelids, or true worms, in which the division into ring-like segments is distinctly visible to the eye. Above the Annelids, and, as I believe, descended from them, are the four classes of the Arthropoda, which are distinguished from the Annelids by the possession of well-developed jointed legs. The classes of Arthropods are as follow:—

Annulosa.

Their lower limit is indefinite, their higher groups have a definite character.

Annelids.

Arthropoda, descended from Annelids.

1. Myriapods (millepedes and centipedes); 2. Crustaceans; 3. True or hexapod Insects; 4. Arachnids (spiders and mites). In these four classes, according to Professor Huxley, the head generally consists of six segments consolidated together. In the Myriapods the number of the segments of the body differs greatly as between species, and, in the lower genera of the class, probably even as between individuals of the same species; but in the Crustacea, Insects, and Arachnids, most species, according to Professor Huxley, have the whole body, including the head, consisting of twenty segments. Such characters as these cannot be adaptive; they must be hereditary, and due to community of origin. These homologies are similar to the fact mentioned in a former chapter, that nearly all the Mammalia, whether their necks are long or short, have seven neck-vertebræ. But this number is subject to variations;[1] and if there are similar variations in the number of segments in the Arthropoda, this in no

Number of segments in head and body of Arthropods.

the Acarus described agrees with *Sarcoptes*, but has an extraordinary maggot-like appearance. The discovery of an external parasite inside an animal, in such numbers as Mr. Robertson records, is very remarkable. Colonel Montagu found such Acari in the Gannet, and Mr. Robertson has since found them in the Pelican." (Quarterly Journal of Science, January 1867.)

[1] P. 247.

degree invalidates the evidence of community of descent; it is only another instance of the truth, that no morphological character is quite invariable. It is to be observed that the determination of the number of segments in an Arthropod is generally difficult, and sometimes impossible, in consequence of the almost perfect obliteration of the joints between some of the consolidated segments, analogous to the consolidation together of some of the vertebræ in all the higher vertebrate forms. But to return to the Acari: these are a family of Arachnids, and, though they are the lowest of all Arthropods, they have not reverted to the worm-like structure; on the contrary, like the rest of the Arachnid class, they have their segments more completely consolidated and less distinguishable from each other than is common among the rest of the Arthropod classes. The same remarks apply to the Pygnogonidæ, a crustacean family of organization so low that they have neither a circulatory nor a distinct respiratory system. Their respiration is through the general surface of the body, as it is in all the lower Invertebrates;[1] and yet their forms are not worm-like, but crab-like. These facts concerning the Acari and the Pygnogonidæ may be, I think, most easily interpreted by supposing that they are tribes which, instead of advancing in organization, have fallen below the general level of the classes to which they belong, and yet have not in any way reverted to the ancestral worm-structure.

Acari, though the lowest Arthropods, do not revert to the worm-type.

Pygnogonidæ.

The first attempts that were made at zoological classification, generally aimed at the arrangement of all species of animals in a single series, according to their affinities, from the lowest to the highest; or rather, as the early schools would have expressed it, from the highest to the lowest. "Naturalists," says Agassiz,[2] "were bent upon establishing one continuous uniform series to embrace all animals, between the links of which it was supposed there were no unequal intervals. The watchword of their school was *Natura non facit saltum;* they called their system *la*

Classification in a single series is impossible.

"Natura non facit saltum."

[1] Carpenter's Comparative Physiology, p. 403.

[2] Spencer's Principles of Biology, vol. ii. p. 299.

chaine d'êtres." The doctrine that *natura non facit saltum* is now almost become an axiom, and is, I think, sufficiently proved by the fact that modern researches among extinct as well as among living organisms have not made known a single type of form fundamentally different from those which have been familiar since the dawn of the science; while they have made known a vast number of intermediate forms, and in some cases (as, notably, in that of the Cirrhipedes) they have filled up a gap by the discovery of a larval form. As it has been truly expressed, "all newly discovered forms can be arranged either *in* known groups or *between* them."[1]

But such expressions as "*la chaine d'êtres*," or "*the organic scale*," are inaccurate. A little familiarity with organic classification is enough to show that no single series is possible which shall represent organic affinities. The possibility of such a series is excluded by the fact that different groups generally approximate by their lower, and not by their higher members. Thus, for instance, among the Vertebrata, if we were to write the names of all the orders and genera of fishes in a series from the lowest to the highest (though not even a single class can be truly arranged in such a series), we could not go on straight to the air-breathing classes; on the contrary, it would be necessary to go back far down in the series of fishes, in order to begin that remarkable series of Perennibranchiate Batrachians which constitutes the transition from the fishes to the air-breathers. It is the same generally. When groups are capable of being compared, though one may be higher than the other on the whole, it is seldom or never that all the members of one group are higher than all the members of another. Thus, though animals are on the whole very much higher than vegetables, the higher vegetables are very much more highly organized than the Protozoa, or lowest animals.

The whole of one group is seldom higher than the whole of a kindred group.

When the student has become convinced of this fact, that the order of organic affinities is not a single series, his

Organic affinities *seem* like a network.

[1] Unless the pseudembryonic forms of the Echinodermata are an exception to this. See Note to last chapter.

first impulse will probably be to conclude that it is an inextricably complex *network*. Such a conclusion would no doubt be incomparably nearer the truth than the notion which it has superseded, of a *chain;* and I think it likely that the majority of naturalists are at present resting in that conclusion. Nevertheless, I believe it will be found, that as the notion of a single chain of affinities rested on a total misconception of the facts of comparative morphology, so that of a network, with affinities in all directions, rests on an incomplete knowledge of them. As already stated, I believe the true form of classification is that of a tree, the branches of which, after diverging, never reunite.

I believe they *are* in form like a tree.

The analogy of a tree may help us further. Were it possible for an intelligent man to see for the first time a large and many-branching tree without knowing anything of its mode of growth, he would at first fancy that its branches formed a network; and it would require a good deal of careful examination before he could be quite convinced that such an inference was a purely visual illusion, and that in not a single case do they reunite after diverging. Just so, I believe the natural and plausible notion of a network of affinities is due to our imperfect knowledge. The organic tree has two main trunks, the vegetable and the animal: these, at least, do not reunite, but diverge and re-diverge into classes, orders, genera, and species, though not with the regularity that appears to be implied in those somewhat technical expressions. I do not say it is proved that groups never reunite after diverging; I only say that I believe every advance that is made in systematic biology and in true classification tends to prove it.

Groups never reunite after diverging.

It is, however, scarcely to be hoped that the outline of the organic genealogical tree will ever be traced in all its parts with even approximate fulness and accuracy. Great progress, no doubt, has been made, and more remains to make. Many connecting links of affinity have been found: some, by the more careful anatomical or microscopic study of organisms already known; others, by the discovery of new forms, fossil as well as living; and

Affinities will probably never be perfectly traced.

others, again, by the discovery of larval forms. And, with the clearer understanding of affinities, we have come to see that some apparent affinities are not real affinities at all, but merely adaptive modifications. Thus the whale tribe are not, as they appear on a superficial view to be, a group connecting the Mammalia with the fishes, but a group of Mammalia modified for an aquatic life, and having no resemblance to fishes except a merely external one. Such a conclusion as this, though merely negative, is as important as any positive conclusion: perhaps more so, for the purpose of clearing away difficulties and anomalies in classification. But it is likely that our organic classifications will ever remain incomplete and in some degree provisional, because the materials of our knowledge are incomplete. Much has no doubt been lost that cannot be recovered. It is probable that whole classes once connected the lower animal forms with the Vertebrata, which have died out during geological time, and, being without shells or skeletons, have left no fossil remains. And, what is quite as important in accounting for apparent gaps in the series, it is likely that forms that once underwent a metamorphosis have ceased to undergo it, and have come to be developed by a direct process. Had the Cirrhipedes lost their metamorphoses and come to be developed directly from the egg, we should probably never have guessed how closely they were connected with the Crustacea; and had they been known only by fossil shells, their resemblance to the Mollusca, which is only external and adaptive, would certainly have been misunderstood, and would have caused them to be mistaken for molluscans. But, though I do not believe that all the gaps in our classifications will ever be filled up, I believe it will before long be generally recognised that affinities are divergent and re-divergent without ever reuniting; as they ought to be on the hypothesis that true classification is genealogical, and that the true bond of affinity is community of descent.

Many links have been discovered, and some apparent links have been found not to be real ones. Whale tribe.

Lost links.

It is to be observed, that on the genealogical theory of classification, affinity by descent does not necessarily involve resemblance; and the groups which are most nearly

Affinity is distinct from resemblance.

akin by descent do not necessarily resemble each other the most. Thus the Cirrhipedes are nearly akin to the Crustacea, though in their mature state they do not resemble them; and if they had lost their metamorphoses, their kindred to the Crustacea would never have been suspected. There may be, and probably are, many such cases in the organic kingdom of real affinity without visible resemblance; and this possibility almost indefinitely increases the difficulty of ascertaining the true classification by descent: just as in human kindreds there is such a thing as family likeness, but the degree of likeness is no measure of the nearness of kindred; brothers are sometimes met with who have no family likeness to each other, and cousins sometimes resemble more than brothers. But in human genealogy we have records or tradition, while we have to make out the facts of organic genealogy as we best can, from the resemblances between the various groups. There is this further parallelism between human and organic genealogy, that in men there are some kinds of characteristics, such as the form of the features, which are original and not acquired, and are consequently in some degree an index to the man's kindred; while there are others, such as peculiarities of voice and of manner, and to a certain extent complexion, which are much more capable of alteration by the action of circumstances, and consequently are no index of kindred. Just so, in organic genealogy there are some kinds of characteristics which are subject to alteration to suit special habits of life, and, as has been already stated, are thus merely adaptive characters, and are of much less value as indications of the real affinities of the organism than those which are not so alterable.

Analogy of human kindreds.

I have shown in this chapter why, as I believe, the branches of the organic tree should diverge and re-diverge. But why should they ascend? Why is there organic progress? The laws of habit and variation may account for variety, for divergence and re-divergence; but why is it that groups, after being formed, generally produce members

Why is there organic progress?

that are superior to themselves in organization, rather than members that are inferior?—for this is implied in the fact that groups generally approximate by their lowest members. In other words, the earliest formed species or classes of a group are generally the lowest; thus, according to the theory detailed in the last chapter, the Batrachia were the first-formed group of air-breathing Vertebrata, and have given origin by descent to the groups above them. The question now before us is, why progress is upward, and not downward; why the later-formed groups are in most cases of higher organization than their ancestors. I shall have to consider this question in the next few chapters.

An exhaustive classification would include not only species but individuals.

I have said that the leading branches of the organic tree diverge and re-diverge into classes, orders, genera, and species. To make the enumeration complete, however, I should have added races, families, and individuals. If it is true that community of descent is the real bond of organic affinity, a really exhaustive classification would include not only every species, but every individual that has ever existed; just as a really exhaustive cosmology would include not only every nebula, every star and planet, and every continent and ocean, but the position of every pebble and the fall of every rain-drop.

NOTE.

Crystalline and organic species.

It has been urged against the validity of the argument from classification in favour of the origin of species by descent with modification, that crystalline species also are naturally classified into groups, and into groups of groups, and yet there is no bond of descent between crystalline species. I think this is sufficiently answered by the fact that the unformed but formative material of organisms can only, so far as we know, be produced by organisms; but this is not true of crystals, as their formative material has a merely chemical source: so that the cases are not parallel.

CHAPTER XXIII.

THE CAUSES OF DEVELOPMENT.

IN the foregoing chapters I have stated a mass of cumulative evidence which, when taken together, amounts, as I believe, to a conclusive proof that species have not been independently created; but that all the species of the same fundamental type *certainly*, and all organic species whatever *probably*, have been descended from the same original stock. I regard it as certain, for instance, that all the Vertebrata are descended from one ancestor, and all the Annulosa from another; and so among plants with Endogens and Exogens. And I regard it as highly probable that those ancestors, in their turn, were descended from a still older stock, which was the original germ of all organisms whatever. I believe that in the chapter on Embryology, especially, I have pointed out the course that has been followed by the successive changes which have developed some of the lower forms into higher forms of the same fundamental type. But I have as yet scarcely approached the question, by what agency the development of one species out of another by descent has been brought about. And if it is true that all organisms are descended from a few original vitalized though unorganized germs, the further question arises, how the matter of those original germs was caused to assume an organic structure; or, in other words, by what causes, acting on vitalized matter, organic structure is produced?

How has the transmutation of species been caused?

How has organic structure been produced?

It is a cardinal principle in scientific reasoning to begin by trying whether known causes are adequate to account for the phenomena under investigation; and it is only when

We must begin by trying

the causes already and independently known to exist are demonstrably inadequate to produce the effects, that we can with any certainty infer from the effects the existence of distinct and separate causes. From this point of view, the questions of the origin of species, and of organization, may be thus stated:— known causes.

Given the laws of the relation of life to matter and energy—or, in other words, given the chemical and dynamical properties of vitalized matter;—given also the laws of habit and variation:—are these, in combination with the action of external causes, sufficient to account for the facts of organization and morphology? Will vitalized matter assume organization under the action of external forces, and in obedience to no other laws than chemical and dynamical ones, and the vital laws of habit and variation?

Before we endeavour to answer these questions, let us go back on the subject, and recount what organization is. Organization, as defined in a former chapter, is the adaptation of structure to function; or, in other words, the adaptation of every part of an organism to every other part, and of all to the mode of life of the organism. It is obvious that if any theory of the origin of organization is to be complete, it must account for histological as well as morphological adaptations; that is to say, it must not only account for the adaptation of the foot for walking, of the hand for grasping, of the wing for flying, of the jaws for masticating, and of other organs each for its own special work; it must also explain how each different kind of tissue has been formed and fitted for its function—bone for support, muscle for transforming vital into motor energy, and the other tissues of which organisms are built up, each for its own peculiar function. These two problems, it is evident, run into each other; nevertheless they are distinct: and it may be thought that the problem of the origin of morphological adaptations—that is to say, the adaptation of every organ to its particular work—is a partly soluble problem; while the origin of histological adaptations—that is to say, the adaptation of every kind of

Organization is adaptation, morphological and histological.

The problem twofold.

tissue to its function—is totally insoluble. And certainly, at a first glance, the question how germinal matter has acquired the power of transforming itself into cellular tissue, bone, muscle, and nerve, appears at least as far beyond the possibility of solution as the question why oxygen and hydrogen combine into water, or nitrogen and carbon into cyanogen. Nevertheless it is worth while to inquire whether it is possible to suggest any physical causes for these transformations: if we come to the conclusion that none such are possible to assign, even such a negative conclusion will be valuable; and if we are compelled to keep our judgment in suspense, it will be well to have stated the question. With respect to morphological adaptations—as, for instance, the question how, and by what physical process or physical cause, a limb which is homologically identical with the pectoral fin of the fish has been transformed into the leg of the quadruped, into the wing of the pterodactyle, the bird, and the bat, and into the hand of man;—with respect to this class of questions, I say, it does not appear so hopeless to seek for a solution. In speaking of the laws of habit and variation in a former chapter, it has been explained at some length how organisms have a very considerable power of adapting themselves to changing circumstances, necessitating a change in the mode of life. The problem before us may be thus stated, in words somewhat different from those employed above:—Is it possible that all of the almost infinitely complex adaptations of the organic creation can be produced by any action, *direct or indirect,* of inorganic forces on the organism, and the actions of the organism in response thereto; the effects of all such actions being, of course, accumulated by hereditary habit, and complicated with the laws of the correlation of variations?

The problem stated.

Two possible processes: self-adaptation, and natural selection.

When I speak of a direct process, I mean, of course, the process of spontaneous self-adaptation to circumstances, of which all organisms are in some degree capable. By an indirect process, I mean that of "natural selection among spontaneous variations," according to Darwin's law. These two causes—self-adaptation and natural selection—are the

only *purely physical* causes that have been assigned or that appear assignable, for the origin of organic structure and form. But I believe they will account for only part of the facts. It is my belief that all such solutions of the problem are inadequate, and that no solution of the questions of the origin of organization and the origin of organic species can be adequate, which does not recognise an Organizing Intelligence over and above the common laws of matter. Or, in other words, I do not believe that the relation of means to purpose in organization is a mere case of the law of cause and effect. This is what I aim at showing in the present and the following chapters. But we must begin our inquiry by considering *how much* of the facts of organic structure and vital function may be accounted for by the two laws of self-adaptation and natural selection, before we assert that any of those facts can only be accounted for by supposing an Organizing Intelligence.

I believe in an Organizing Intelligence, over and above these, distinct from physical causation.

Here I must guard myself beforehand against a misconception. I shall be compelled to say that some organs and structures may have been formed by the forces of ordinary matter acting on and through the laws of Habit, while other organs and structures can only be the work of Intelligence. But this is not an accurate way of speaking. It is only a concession to that narrowness of our understanding which compels us to think and speak of things apart which in nature are always and necessarily united. Life does not suspend the action of the ordinary forces of matter, but works through them. I believe that wherever there is life there is intelligence, and that intelligence is at work in every vital process whatever, but most discernibly in the highest. In every vital action, whether formative, motor, or sensory, whether conscious or unconscious, the ordinary forces of matter are at work, directed and controlled by life and intelligence. But, though I believe that these two sets of causes act in every manifestation of life,—the forces of inorganic matter on the one hand, and life with intelligence on the other,—it is a mere statement of obvious fact to say that the inorganic causes are most discernible in the lower vital

Where life is, there is intelligence: and most discernible in the highest functions.

functions, as in nutrition, circulation, and respiration ; and life and intelligence are most discernible in the formation and in the action of the organs of sense and of thought. Nutrition, circulation, and respiration are in a great degree to be explained as results of physical and chemical laws; and I believe that, as I shall endeavour to show, the origin of the organs in which those functions are carried on may be in some degree explained by the operation of those same laws. But sensation, perception, and thought cannot be so explained. They belong exclusively to life; and, similarly, the organs of those functions—the nerves, the brain, the eye, and the ear—can have originated, I believe, only by the action of an Organizing Intelligence.

The laws of habit are not intelligent.

I believe intelligence to be a concomitant of all life, but I do not think that all the laws of life are to be referred to vital intelligence. The laws of Habit are purely vital laws, but I do not see any element of intelligence in them.

I have now to explain in what way I think that some of the simpler of the formative processes of organization may be accounted for by the action of inorganic forces on vitalized matter. What follows on the origin of cellular tissue, of circulatory vessels, and of respiratory organs, is all suggested by the second volume of Herbert Spencer's "Principles of Biology," and is mostly taken from it.

We have seen that in most cases, though not in all, the first product of organization is the cell. Many of the lowest Algæ consist of but a single cell, and the embryo of the higher plants and animals before they begin to assume any distinctive form consist of cellular tissue. A very probable cause of the first formation of cells is that various influences from without acting on a minute mass of vitalized but unorganized matter, determine a slight hardening of the surface. The exact nature of the action is probably undiscoverable; but all I wish to insist on is, that it must be due to some agency that acts differently on the inside and on the outside of the mass of germinal matter. By

Formation of cellular tissue.

repetition of this process, a habit is produced of forming cells; and this becomes hereditary, so that cells continue to be produced in the midst of the germinating seed or of the growing embryo, and other situations where the chemical actions are alike in the inside and on the outside of the cell, and where consequently cells could not continue to be formed in the same way that I suppose them to have been formed at first.

This is a mere speculation, and, so far as I am aware, has no evidence except what it derives from internal probability. But there is more direct evidence as to the origin of circulatory vessels. We know that streams have excavated their own channels, and there appears to be a very strong probability that the circulatory channels in organisms have been formed by the flow of the nutritive fluids. It is stated on the high authority of Von Bär, that in the animal embryo blood appears before blood-vessels are formed, and circulation begins before there is a heart to propel it;[1] and we know that the embryonic states of the higher forms generally represent the permanent states of the lower ones. We may consequently infer that the earliest circulation was not due to the action of a heart, or to muscular action at all. The circulation in air-breathing plants is principally due to evaporation from the leaves, but this will not apply to aquatic or embryonic organisms. A physical cause for their circulation, however, may be assigned. It has been ascertained[2] that if two liquids have access to the same capillary tube, and one of these has a stronger affinity than the other for the substance of the tube, the one that has the strongest affinity will drive the other before it. Arterial blood has a stronger affinity

Circulatory vessels, how formed.

Cause of circulation in air-breathing plants;

[1] Carpenter's Comparative Physiology, p. 717.

[2] Carpenter's Human Physiology, p. 255. The discovery of this law, and its application to the facts of circulation, are ascribed to Professor Draper. Of course it is true of porous substances, as well as of capillary tubes.

This law will account for the capillary circulation in the respiratory organs, as well as throughout the tissues. Throughout the tissues, the arterial or oxygenated blood is attracted by the carbon of the body. In the respiratory organs, the venous or carbonated blood is attracted by the oxygen of the lungs.

and in the lowest animals.

than venous blood for the substance of the tissues; and Dr. Carpenter regards this action as being probably at least one cause of the capillary circulation. Some such action as this must probably be the cause of the motion of the nutritive fluid, not amounting to circulation, which has been observed in the Sertularian Hydrozoa. These animals have nothing of the nature of a heart, and yet the nutritive fluid, which corresponds to the blood of the higher animals, flows towards growing parts, and away from dying ones.[1]

Tendency of circulation to form channels for itself.

Suppose now that a movement of the nutritive fluid—of sap or blood—by permeation through the cellular tissue, has been commenced, whether by this means, or, as in plants, by evaporation from the surfaces exposed to air and sunbeams;—and if proof is needed that the circulation of air-breathing plants is so caused, it is proved by the fact that there is hardly any circulation in the water-breathing kinds;—suppose, I say, that the circulation has begun from either of these two causes, or from any other; the currents will tend to excavate channels for themselves through the cellular tissue, exactly as rivers tend to excavate their own channels; and the formation of such channels will become hereditary. This is no mere hypothesis; it has been as directly verified as the nature of the case admits of. A perfect gradation may be seen in air-breathing plants, from cellular tissue to perfectly-formed vessels. First, ordinary cellular tissue; next, cells elongated in the direction in which the sap flows, as determined by the place of greatest evaporation; next, cells having their separating walls broken or dissolved away, so as to unite them into tubes; finally, tubular vessels showing no longer any vestige of cell-structure. I do not mean that this whole course of development takes place in the lifetime of any one plant; but the comparison of these transitional stages makes it highly probable that such has been the course of development through successive generations; and there are many cases where a part of the transition may be witnessed in the individual.[2]

[1] Carpenter's Comparative Physiology, p. 633.

[2] For details see Spencer's Principles of Biology, Part V. chap. iv

I now come to the organs of respiration; and I have to begin this subject with the remark, that among the lower tribes of animals generally, those organs are surprisingly inconstant, not only as to their position, but as to their existence. This, I think, is more remarkably the case among the water-breathing Gasteropodous Mollusca than in any other class, but it is generally true of the aquatic Invertebrata; and in close connexion with this is the fact, that the most remarkable cases in the animal kingdom of organs that assume new functions totally unlike their original ones are among respiratory organs. This extraordinary plasticity of the respiratory organs is evidently connected with, and I believe is a result of, the fact that among the lowest animals, and in some degree among the highest, the function of respiration belongs to the whole surface. "The alimentary canal respires, digests, and excretes in the larva of the dragon-fly and in the fish Cobites,"[1] neither of which is a very low organism. Among the Batrachia a great proportion of the respiration takes place through the skin;[2] in the axolotl, which is one of that class, the importance of the branchiæ is so slight that their removal does not appear to injure the animal, or even to increase the necessity for coming to the surface of the water in order to breathe air;[3] and even in man there is a slight amount of respiration through the skin.[4] I believe it may be safely asserted that all land animals have distinct respiratory organs.[5]

Respiratory organs: their variability.

Respiration, though it takes place in living beings, is essentially a merely chemical and physical process; it consists in absorbing oxygen, and giving out the carbonic

Respiration is a physical process.

[1] Darwin's Origin of Species, p. 220.

[2] Carpenter's Human Physiology, p. 293.

[3] Memoir by Auguste Dumeril, translated in the Annals of Natural History, December 1867.

[4] Carpenter's Human Physiology, p. 293.

[5] Those of the earthworm have remained unknown till lately. But it is now stated that its "respiratory apparatus is an aqueous sac, lined with vibratile cilia, within the abdominal cavity, on either side of the body." (Dr. Coote on Nerve Structure and Force, Quarterly Journal of Science, April 1867.) The respiratory organs of the land mollusca are well known.

acid which is formed by slow combustion throughout the body. The means by which the organism effects this change is to bring the blood into virtual contact with the air or water, according as the animal is an air- or a water-breather, over an extensive surface of very thin membrane, through which the exchange takes place spontaneously by that physical process known as the "diffusion of gases."[1]

Possible origin of respiratory organs.

If now in one of those animals, such as many of the naked marine Mollusca, in which the function of respiration is discharged by the whole surface of the body, and there is no distinct respiratory organ;—if in one of these, I say, a part of the skin, from any spontaneous variation, becomes thinner than the rest, or more abundantly supplied with blood-vessels; or if the blood under one part of the skin contains a somewhat larger proportion of carbonic acid, from the waste of the body, than in other places; any one of these causes will produce a more rapid exchange through that part of the skin than through any other, between the carbonic acid of the blood and the oxygen of the external medium, and that part will be a rudimentary, or nascent, respiratory organ; the flow of blood to and through that part will be increased by the chemical unlikeness between venous and arterial blood, in virtue of the law already stated; and it appears tolerably well established, that an increase in the flow of blood through any part will cause it to grow and develop.

In order to form a complete theory of this subject, it would be necessary to explain, further, why the nascent respiratory organ not only develops, but develops into that structure which is specially needed for the purpose of respiration. This, however, I am not able to do, and I doubt whether it is possible. Unlike the origin of cellular tissue, or the formation of sap-vessels by the union of cells, the present problem is an extremely complex one.

Whatever may be thought of this speculation (and I only advance it as such), it is consistent with what we know of the development of the branchiæ of the Mollusca,

[1] Carpenter's Human Physiology, p. 264.

which arise by budding from the skin of the embryo.[1] For if embryology is an index of descent (and this, I think, cannot be reasonably doubted), we must suppose that the development of the individual repeats, in a short time, the development which occupied untold generations of the species. It can scarcely be necessary to repeat, that all actions whatever, tending to modify the nature of an organism, will accumulate their effects through successive generations.

I will now go on to mention two remarkable instances, in which organs originally employed for another purpose have become converted into respiratory organs. These two instances include the principal, though not the only classes of air-breathing animals.

Homologies of the respiratory organs of insects:

The leech and the earthworm have two small sacs in each segment opening on the external surface of the body. The function of these appears to be to secrete mucus. But there is a gradation, through the Millepedes and Centipedes, between these sacs and the air-tubes or tracheæ by which insects respire.[2] The tracheæ of the insect are consequently homologous with the mucus-sacs of the worm; and, if the development theory is true, the sacs, being no longer needed for the purpose of secreting mucus, have, through successive generations, changed the character of their lining, and have extended through the body, so as to become transformed into respiratory organs, adequate to meet the wants of such active animals as insects. What made the transformation possible, was the fact that every surface exposed to the air or the water in which the animal lives is (if not too much indurated, like the shell of a tortoise or of a crab) in some degree a respiratory surface.[3]

The wings of insects are due to a transformation which is even more wonderful than this. Unlike the wings of Pterodactyles, birds, and bats, they are in no way homologous with legs; on the contrary, they are now generally believed to be appendages of the respiratory system; the

[1] Spencer's Principles of Biology, vol. ii. p. 293.
[2] Carpenter's Comparative Physiology, p. 748.
[3] Carpenter's Human Physiology, p. 293.

only organs with which they are homologous are the leaf-like expansions that arise from the openings of the tracheæ of some aquatic larvæ; though it is very difficult to guess by what kind of a process leaf-like branchiæ came to be used as wings. The difficulty is not so much to understand how the wing-form was produced (for branchiæ may be produced in one form almost as easily as in any other), as to understand how the habit of flight could originate; for, as a rule, there are no sudden transitions in nature. But it is to be remembered that motor habits are more variable than formative ones.

of air-breathing Vertebrata.

The next transformation that I have to mention is not only one of the most important, but one of the best understood, in the whole organic creation. I mean the transition from the swim-bladder of fishes to the lungs of the air-breathing Vertebrata. I have spoken of this several times already; but I have now to notice the significant fact that all the Batrachia, through which class the transition takes place, are inhabitants of fresh water.[1] Fresh water is liable to be dried up; and I believe the Batrachians to be descended from fishes, which, when water was failing them, acquired the power of breathing air by means of the swim-bladder.[2] This would be almost incredible, were it not for the general fact of the inconstancy of the form and position of the respiratory organs, and the special fact of the preservation of the Perennibranchiate order, which presents a series of connecting forms. And what still further strengthens the case, is the remarkable set of facts lately discovered concerning the axolotl. This animal is a Batrachian, and has till now been regarded as a Peren-

Origin of the latter.

The axolotl.

[1] Except the land-newt, or land salamander, and perhaps one or two other species, which are not aquatic at all.

[2] See Spencer's Principles of Biology, vol. i. p. 395, and vol. ii. p. 325. I must say, however, that I think his attempt to account for the origin of the swim-bladder is quite unsuccessful. He thinks it arose from fishes acquiring the habit of swallowing bubbles of air, at a time when the supply of oxygen in the water was failing in consequence of the increasing heat of the weather. This appears to be possible only in shallow fresh waters, and I do not think there is the slightest reason for believing cod and other sea-fish that have swim-bladders to be descended from fresh-water species.

nibranchiate. But the axolotl as hitherto known, though it is a mature form by the usual test of being able to propagate,[1] proves to be a larva in the sense of having yet to undergo metamorphosis. The specimens observed in captivity in France, from which alone our knowledge of their metamorphosis is derived, sometimes undergo metamorphosis and sometimes not, without any assignable reason. Like other Batrachians, they lose their branchiæ when they undergo metamorphosis, in addition to other changes; and if the branchiæ are removed (under which operation the animal does not appear to suffer in health), the chance of the metamorphosis taking place is increased, though it is still very uncertain.[2]

These facts are most interesting, partly as showing that an animal which has not undergone its final metamorphosis may yet propagate; and partly as showing how variable is the fact of fianl metamorphosis, as between individuals of the same species. This last is an instance of the general law, that those characters which are variable as between allied species are also variable as between individuals of the same species: for no one doubts the real and near affinity between the Perennibranchiates, which never lose their branchiæ and are in fact permanent tadpoles, and the Caducibranchiates, such as the newt and the frog, which lose their branchiæ when they cease to be tadpoles.[3] The irregularity of the metamorphoses of the axolotl suggests also, that the first individual of a Perennibranchiate species that lost its branchiæ, and gave origin to a race of Caducibranchiates, may have done so accidentally, in consequence probably of the branchiæ drying up and withering for want of water.

[1] *I.e.*, sexually. No vertebrate ever propagates in any other way.

[2] Memoir by Auguste Dumeril, translated in the Annals of Natural History, December 1867.

[3] I do not mean to imply that it would be a natural classification to divide the Batrachia into Perennibranchiates and Caducibranchiates. The right division of the class is into (1) the newt or salamander tribe, having four limbs and a tail; this includes the Perennibranchiates: (2) the frog tribe, having four limbs but no tail: (3) the Cæcilia genus, which are like serpents in form, having no limbs.

A fact may be mentioned of the vegetable kingdom, which is strictly analogous with the power of various parts of the external surface of animals to assume the respiratory function. Leaves are the organs with which plants decompose the carbonic acid of the atmosphere; but there are some tribes of plants, of which the Cacti are the best known, that have no true leaves; and in them the stems are green like leaves, and discharge the function of leaves. And it belongs to the same order of facts, that one secreting organ frequently shows itself able, though imperfectly, to discharge the function of another. This has been observed in cases of disease in man, and in animals when one of the organs has been removed or otherwise experimentally interfered with.[1]

Stems taking the functions of leaves.

Inter-change of function between secretory organs.

I have now brought forward a number of facts and arguments, which all tend to show that *up to a certain point* tissues and organs are capable of being formed by the action of purely physical forces on vitalized matter. But it is important to observe, that all the instances I have mentioned are taken either from the vegetable kingdom, or from the vegetative, or nutritive, systems of animals; and no way appears conceivable by which the actions of external forces on the organism can account in any similar way for the origin of the peculiarly animal tissues—for the formation of muscle and nerve. If their origin is explicable at all, it must, I think, be due, not directly to the action of inorganic forces on the organism, but to the actions of the organism itself in response to impressions from without. But a satisfactory physical theory of the origin of muscle and nerve is out of the question in the present state of science, nor do I feel sanguine of ever attaining to it. I only do not say it is impossible.[2]

Will purely physical actions account for the origin of all structures?

[1] Carpenter's Human Physiology, p. 374.

[2] I say this after reading the speculations on this subject in the second volume of Spencer's Principles of Biology. He admits that his theory of the origin of nerve-fibres does not account for ganglia. Now nerve-fibres and ganglia are always found together, in all classes of animals, and they are developed together; so that no theory is good for anything that

One of the most important laws to be borne in mind in all speculations of this class, is that law in virtue of which every organ improves with use. This indeed is a particular case of the law of self-adaptation. Exercise, provided that it is not beyond the limit of what is good for health, increases the strength of a muscle or the sensitiveness of a nerve. The difficulty is not to account for almost indefinite improvement in an organ, but to account for its origin. I cannot make any suggestion whatever as to the possible origin of nerve, but perhaps it is not absurd to think that the fibrous structure of muscle was originated by the sarcode substance of the earliest structureless though living beings acquiring the habit of contracting in one direction more readily than in any other. We know that the sarcode has contractile power in organisms which have no visible structure, and the simplest rudimentary muscular structure consists in a fibrillation of the sarcode.[1]

Organs improve with use: the difficulty is first origin.

Origin of nerve and muscle:

I have now stated my belief that some of the simpler structures belonging to the vegetative system have probably been produced by the action of inorganic forces on the organism; and that muscular structure may possibly, though I do not say probably, have been produced by the action of the organism itself in response to impressions from without. Of course these two factors are always both present, though acting in very unequal proportions in different cases. But there are structures for the origin of which it is, I believe, utterly impossible to account by any such merely physical theory; and which can only be referred to an organizing intelligence. I refer to such organs as the eye and the ear. If it is certain, as I think it is, that the flow of the nutritive fluids through cellular tissue, for successive generations, must have a tendency to form a rudimentary circulating apparatus, it is at least equally obvious that the action of light falling on the eye for any number of generations can have no similar tendency to produce the optical apparatus of the eye. Nor can the

of the eye and the ear.

attempts to account for the one without the other. It would be different if the ganglia were an *outgrowth* of the fibres, as the brain is of the spinal cord.

[1] Dr. Wyville Thomson on the Embryology of the Echinodermata, Natural History Review, October 1864.

constant exercise of the eye in the act of seeing have any such effect. The exercise of the eye, within the limits of what is healthful, does no doubt tend to increase the sensitiveness of the retina; and I do not say it is impossible, though I do not admit it as probable, that the muscular arrangements to which the mobility of the eyeballs and eyelids is due may have been produced by the effort to move them, continued through successive generations; and that the expansion of nerves over the retina may have been produced by the constant stimulation of the nerves themselves. But no such merely physical theory will account for the origin of the special complexities of the visual apparatus. Neither the action of light on the eye, nor the actions of the eye itself, can have the slightest tendency to produce the wondrously complex histological structure of the retina; nor to form the transparent humours of the eye into lenses; nor to produce the deposit of black pigment that absorbs the stray rays which would otherwise hinder clear vision; nor to produce the iris, and endow it with its power of partly closing under a strong light so as to protect the retina, and expanding again when the light is withdrawn; nor to give the iris its two nervous connexions, of which one has its root in the sympathetic ganglia, and causes expansion, while the other has its root in the brain, and causes contraction.[1]

No physical causes will account for the origin of the eye and the ear;

I have spoken first of the organs of special sense, because it is in their case that the impossibility of formation by any physical action is most obviously evident. But there are other cases where the impossibility is equally demonstrable. When any structure is formed or modified either by the action of external forces, or by the action of the organism itself, this is a case of self-adaptation—not of adaptation only, but of self-adaptation. But, as we have seen, the complexities of the eye and of the ear cannot be so produced; and, quite independently of any special complexity, there are many structures in which the relation of structure to function is such as to make any physical explanation of their formation as totally impossible as in the case of the eye and the ear, though for an entirely

[1] Carpenter's Human Physiology, p. 639.

different reason. Take the case of protective structures; the skin hardens and thickens in any place that is exposed to rough usage; this is a case of self-adaptation, and it may become hereditary, as in the instance of the knuckles of the gorilla.[1] But such cannot be the origin of the shell that protects the bird's egg. Without this protection, no egg could be hatched, and the whole tribe of birds would perish. But the contact of comparatively hard and rough substances, which makes the shell necessary, cannot have had the slightest tendency to produce the shell; for the shell is formed, and from the necessity of the case must be formed and completed, before any such contact can take place.[2] And the law of hereditary habit, universally true as it is, makes no difference here; for it appears utterly impossible that egg-shells can ever have been formed under different circumstances from the present. The same is true of the bony or cartilaginous skulls that protect the cephalic ganglia in the Cephalopoda (cuttlefish and nautilus), and in the Vertebrata, and of the hard woody shells that protect the seed in nuts. The fact that there is something to protect, is not a *physical* cause of the production of a protective structure.

nor of the egg-shell,

nor of the skull,

nor of nutshells.

In this chapter I have considered how far the facts of organization can be accounted for by the direct action of inorganic forces on the organism, and by the actions of the organism itself; and I have come to the conclusion, that such a purely physical account of the origin of organization is probably valid in the case of some of the simpler structures belonging to the vegetative system; very doubtful in the case of the peculiarly animal ones, as muscle and nerve; and demonstrably, not merely inadequate, but totally inapplicable to the case of the complexities of the organs of special sense, and to many cases, not necessarily complex ones, in which the structure is produced under such circumstances that the peculiar work for which it is adapted can have no tendency to originate it. In the next chapter I shall have to consider how much may be explained by the law of Natural Selection.

Summary.

[1] Spencer's Principles of Biology, vol. ii. p. 295. [2] Ibid. vol. i. p. 440.

CHAPTER XXIV.

NATURAL SELECTION.

IN the chapter on Distribution, while stating my belief that the remarkable similarity, without identity, between the living species inhabiting the same region during successive geological periods is due to the bond of descent, I said also that the species inhabiting any region at present are not the direct lineal descendants of those which dwelt there in the last geological age; but that the descent has been modified in accordance with a peculiar law. The law I mean is that of "natural selection, or the preservation of favoured races in the struggle for life." (I quote these words from the title-page of Darwin's work on "The Origin of Species.") But as Darwin's work, in which the law of natural selection was first stated and proved, is a well-known and very readable book, it is needless for me to go into much detail. I speak of it as a law that is proved. There is the greatest possible difference of opinion as to how much the law will account for; but no one who has the slightest knowledge of the subject can doubt that it is a truly operative law.

Natural selection defined

Before there can be selection, there must be something among which to select; and the full designation of the theory is "natural selection *among spontaneous variations.*" In the chapters on Habit and Variation, we have seen that species are not absolutely constant in their characters, but are liable to slight, and sometimes considerable variations, which may become very great if they are added up and accumulated through successive generations. We have seen also that variation is stimulated by change of the

to be among spontaneous variations.

circumstances of life and by mixture of races, when these do not go further than what is good for the health and vigour of the species; and that some species are more variable than others. It has also been shown that when any particular character in a race once begins to vary, it is apt to acquire a habit of varying; and it is obvious how this fact must facilitate the accumulation of variations through descent in particular directions. I mean that when any one character becomes variable, such as the form of the beak in the domestic pigeon, it will be comparatively easy to obtain by selection new breeds that differ from the parent ones in that point.

Causes of variation in domestic races.

Domestication is a great change in the circumstances of the life of both animals and vegetables, and cross-breeding, so as to produce slight mixtures of race, is systematically practised with many of the domestic races of animals; and these two causes are amply sufficient to account for the great variability which is common, though perhaps not universal, among domesticated races, vegetable as well as animal. It is, I think, an unsettled question, whether a perceptible degree of variation ever takes place, at least among the higher animals and vegetables, without the stimulus either of change of circumstances or of mixture of race; and it will not be easy to decide the question, for evidence is difficult to obtain concerning wild races, and the variability of the domestic ones is probably due to the change in the conditions of their life effected by their first domestication, and to subsequent crossings of the breed.

Changes of circumstances in geological time.

But it is certain that changes in the circumstances of life must, throughout geological time, be constantly occurring, and stimulating variation. Geological, and I may add astronomical,[1] revolutions alter the climate and physical geography of whole continents; and quite independently of this, geological revolutions effect vast changes in the circumstances of the life of species, by either forming

[1] See Mr. Croll's Papers on the Glacial Climate, and kindred subjects, in the Philosophical Magazine. I do not agree with all his results, but I think he has done great service to science by showing that the changes in the earth's orbit must produce climatic changes.

or removing barriers to migration. Besides—as Darwin was, I believe, the first to state, with any emphasis proportioned to the importance of the fact—any change in the distribution of one species is almost certain to produce changes in the conditions of the life of other species, by altering the character and abundance of their food, the character and number of their enemies, and the character of the species with which they have to compete for a subsistence. The importance of this element of competition, or "struggle for existence" (to quote again from Darwin's title-page), was also first insisted on by Darwin. I shall have to return to this subject shortly. It is very difficult to say how much effect is to be ascribed to mixture of races occurring in a state of nature. Among plants the pollen of one is carried to the stigma of another, by the wind or by insects, quite at random; and in this way races may be mixed. But, for reasons to be explained further on, it is not common for two varieties of the same species to be found in the same habitat, and this must tend to prevent mixture. The same is true among animals; and besides, among the higher animals, which have a mental nature and a power of choice, it seems certain that this will be exercised in a way that will keep races separate.[1] For these reasons, I am inclined to think that there is very little mixture of races in a state of nature, and that the stimulus to variation is chiefly given by changes in the circumstances of life.

Struggle for existence.

Races probably mix little in nature.

Having spoken of these preliminary questions, it is time to state the manner in which natural selection will take place.

Rapid increase.

All organisms multiply so rapidly that when any geological or climatic change opens a new habitat to a species, a time which is geologically very short will suffice to stock the new habitat with as large a population of that species as it can support; and when this has been done, many more

[1] This is true of domestic races. When any degree of freedom is permitted, different breeds of the same species, as sheep or pigeons, prefer to herd and to breed each apart. (Darwin on Variation under Domestication, vol. ii. chapter xvi.)

individuals are born every year than can possibly come to maturity. Consequently there will be a "struggle for existence." If any spontaneous variation takes place which gives an advantage in that struggle to its possessor, the individual so favoured will have the best chance of surviving and leaving offspring, and the favourable variation will probably be inherited. Thus, by preserving the best and weeding out the inferior ones, the race will be gradually improved. This process is exactly the same in principle as that by which the breeds of domestic plants and animals have been improved; the best are preserved, and the others are destroyed or not permitted to breed.

Favourable variations will be preserved and inherited.

This short explanation will make it obvious how selection, whether by natural or by human agency, can improve and perfect a breed. But it must be further explained how selection can produce, from the same parent stock, two or more races differing not only from the parent stock, but from each other. For this purpose, however, it is only necessary that selection should act on two different and divergent lines of descent, and that the individuals selected in the different lines should be selected for different qualities. The various breeds of the dog, for instance, have chiefly arisen by selection under domestication; and they are distinct, because selection has been applied for different purposes in the different breeds: in some for fidelity and sagacity; in others, for power of hunting by scent; in others, again, for fleetness. I believe this account of the origin of the breeds of dogs is historically true; it is certainly possible; and there cannot be the slightest doubt that such has been the origin of the domestic breeds of the pigeon,[1] which vary from each other more than those of any other domestic animal. Selection, constantly applied for different qualities, must necessarily give origin to distinct breeds, because the different qualities can be but seldom found together in any unusual degree. Thus, among dogs, if the qualities of keenness of scent and fleetness are not correlated, which they certainly are not; and

Divergence of character, how produced by selection in domestic races,

[1] Darwin's Origin of Species, p. 24.

if one dog in every hundred excels in one of those qualities, and the same proportion in the other, to a sufficient degree to attract the attention of the selector; the chance of any dog excelling in both will be only the second power of one in a hundred, or one in ten thousand, which chance is so small that it may be left out of account.

and in wild races.

It is obvious that selection by natural agency may act in exactly the same way as selection by human agency. Wild beasts of prey that excel either in fleetness or in scent will have the best chance of surviving and leaving offspring; and these favourable variations will be added up and accumulated through an indefinite number of generations. As I have just shown, it is not at all likely that two favourable variations will occur in the same individual; and an unusual degree of fleetness in one of a race that hunts by scent, or an unusual power of scent in one of a swiftly running race that hunts by sight, would probably be comparatively useless, and consequently would not tend to the preservation of that individual. What will be most valuable, and consequently most conducive to the preservation of the individual, is probably a slightly increased degree of some favourable peculiarity that the race already has in a tolerably high degree; especially as, by the laws of self-adaptation and hereditary habit, the race will have begun to be adapted in its whole structure to the mode of life to which its favourable peculiarity is suited. Thus we may expect sagacity and wariness to become characteristic of those animals which hunt by scent, especially if they are gregarious. Besides, a race produced by the selection of individuals for any one character will necessarily have that character, on the whole, more variable than the rest of the organism; and, as we have seen in speaking of the laws of variation, a character, or an organ, that begins to vary is apt to continue variable; so that favourable variations will be more likely to occur in the character that constitutes the principal differentia of a breed, than in any other of its characters. It is, as already stated, an observed fact that this is so. For these reasons, different breeds will continue distinct and divergent.

How will incipient races be kept apart?

Here occurs a difficulty which Darwin appears not to see, but which H. Spencer thinks fatal to the theory as applied to the highest animals. Among animals that unite for each birth and wander much, will not variations, no matter how favourable, be lost and merged in the second generation, by the union of the individual possessing the favourable variation with others that are without it?[1] It is quite obvious that the domestic breeds of animals could not be kept distinct, if free inter-breeding between different varieties were permitted.[2] I am inclined, however, to think that this objection is sufficiently answered by the fact, that most varieties in a state of nature are local varieties: so that while natural selection is forming a variety, suited to the locality, by preserving the individuals suited to it and destroying the rest, this action will not be much interfered with by the race getting crossed with other varieties. Dissimilar habits of life will also probably have considerable effect in keeping the individuals of different races apart: and, as we have seen, races are kept apart by their instincts among the higher animals, and probably among all animals.

By being local.

How wild races are kept distinct.

I believe that natural selection will account for much which self-adaptation will not account for.[3] To take one very curious instance: so far as I can see, natural selection is capable of giving origin to the bat's wing. Once the wing is formed, self-adaptation will no doubt give the necessary power to the wing-muscles; but self-adaptation cannot, I think, have any tendency to produce that ex-

Origin of the bat's wing.

[1] Spencer's Principles of Biology, vol. i. p. 454.

[2] "The prevention of free crossing, and the intentional matching of individual animals, are the corner-stones of the breeder's art. No man in his senses would expect to improve or modify a breed in any particular manner, or keep an old breed true and distinct, unless he separated his animals." (Darwin's Variation under Domestication, vol. ii. p. 85.) "Cats, which from their nocturnal habits cannot be selected for breeding, do not yield distinct races in the same country." (Ibid. vol. ii. p. 236.)

[3] I may here mention Darwin's belief, that what is called the acclimatization of a race of plants is really, in some cases, the production of a new and hardier race by selection. It is obvious that natural selection may operate among plants grown in a garden but not under glass, by killing the least hardy and preserving the most so. (Origin of Species, p. 169.)

tension of the fingers, and of the skin over the fingers, which constitutes the wing.

Extract from Darwin.

The bat's wing, when in the nascent state, probably resembled the parachute of the flying squirrels. I quote the following from Darwin:[1] "Look at the family of squirrels: here we have the finest gradation from animals with their tails only slightly flattened, and from others, as Sir J. Richardson has remarked, with the posterior part of their bodies rather wide and the skin on their flanks rather full, to the so-called flying squirrels; and flying squirrels have their limbs and even the base of the tail united by a broad expanse of skin, which serves as a parachute, and allows them to glide through the air to an astonishing distance from tree to tree. . . . Let the climate and vegetation change, let other competing rodents or new beasts of prey immigrate, or old ones become modified, and all analogy would lead us to believe that some at least of the squirrels would decrease in numbers or become exterminated, unless they also became modified and improved in structure in a corresponding manner. Therefore I can see no difficulty, more especially under changing conditions of life, in the continued preservation of individuals having fuller and fuller flank-membranes, each modification being useful, and each being propagated, until, by the accumulated effects of this process of natural selection, a perfect so-called flying squirrel was formed.

Flying squirrels.

Flying lemur.

Now, look at the Galeopithecus, or flying lemur, which formerly was falsely reckoned among bats. It has an extremely wide flank-membrane, stretching from the corners of the jaw to the tail, and including the limbs and the elongated fingers: the flank-membrane is also furnished with an extensor muscle. Although no graduated links of structure fitted for gliding through the air now connect the Galeopithecus with the other Lemuridæ, yet I see no difficulty in supposing that such links formerly existed, and that each had been formed by the same steps as in the case of the less perfectly gliding squirrels; and that each grade of structure was useful to its possessor. Nor can I

[1] 'Origin of Species,' p. 208.

see any insuperable difficulty in further believing it possible that the membrane-connected fingers and fore-arm of the Galeopithecus might be greatly lengthened by natural selection : and this, as far as the organs of flight are concerned, would convert it into a bat. In bats which have the wing-membrane extended from the top of the shoulder to the tail, including the hind-legs, we perhaps see traces of an apparatus originally constructed for gliding through the air rather than for flight."

Bat and flying lemur not descended from a squirrel.

It may be necessary to state distinctly, that no one supposes the bats or the flying lemur to be descended from a squirrel. The unlikeness of the other parts of the organism excludes this. But Darwin believes, and I agree with him, that their wings have been produced by the improvement of an organ which originally resembled the parachute of the flying squirrels.

I mention this instance as the best I can find, of organs that may have been produced by natural selection, and cannot have been produced by any process of self-adaptation. The membranes of the flying squirrel, the flying lemur, and the bat, are simple organs ; and those of the flying squirrel, at least, are not closely connected with the other parts of the organism : that is to say, their presence does not cause any very great deviation from the usual structure of squirrels. These two facts, that the membranes in question do not consist of a number of correlated parts, but are simple organs, and that they have no close correlation with the other parts, make this a peculiarly good case to isolate in thought, so as to make it the subject of reasoning. It is certain that the flying squirrels can take much longer leaps than they could if they had no membranes, and it needs no proof that this power must be useful to them. But it is, I think, equally obvious, that the habit of leaping cannot have any tendency to develop such membranes, or to increase their size after they begin to be developed. Self-adaptation thus fails to account for this very simple change. Natural selection, however, here comes into play. I agree with Darwin in thinking that the preservation, for generation

Membranes not produced by self-adaptation, but by natural selection.

after generation, of squirrels that had the fullest skin on their flanks, and were thus best able to escape their enemies by taking long leaps, is quite an adequate cause for the origin of such a structure as the membrane of the flying squirrel. Further development into such a perfect flying apparatus as that of the bat is a much greater change than that from the common to the flying squirrel; but self-adaptation will account for this in a great degree; once the animal began to gain anything by flapping its membranes, the muscles used in doing so would strengthen and grow, in virtue of the law that every muscle strengthens and grows with use. There is no difficulty in believing that it would begin to flap its membranes as soon as it became useful to do so; if mere animal intelligence were not sufficient to originate such an instinct, it might begin in some spontaneous variation, much less strange than that in which the characteristic habit of the tumbler pigeon began. This is exactly the same as the question how animals with legs first learned to creep and to walk.

Origin of the bat's wing.

I agree with Darwin in believing that natural selection can produce changes which self-adaptation has no tendency to produce. But the process of self-adaptation, in whatever direction it is going on, will be so furthered and assisted by natural selection that the effects of the two will be impossible to separate. Self-adaptation gradually adapts organisms to their mode of life; natural selection destroys those which are least adapted; and it is obvious that when these factors are both in operation, they will work to the same result.

Self-adaptation and natural selection co-operating.

But is this explanation of the probable origin of the bat's or the flying lemur's wing satisfactory? Does it explain all the facts? I greatly doubt whether it does. I do not see how it will account for the fact that in the flying lemur "the flank membrane is also furnished with an extensor muscle."[1] I do not think that any clear evidence has been brought, proving that either self-adaptation or spontaneous variation will suffice to produce a new muscle. But there are so many instances of organs

Extensor muscle of wing of flying lemur.

[1] See quotation from Darwin above.

which appeared to be quite peculiar, proving to be really homologous with organs in other species,[1] that I attach little weight to such an objection. I only mention it as an unsolved difficulty, without implying that it is an insoluble one. If the extensor muscle of the flying lemur's wing-membrane can, for instance, be shown to be homologous with some muscle in any other lemur, similar to those muscles by means of which the horse shakes his skin when tickled, it will be safe to infer that the two muscles are the same in origin, but modified for different work by habitual self-adaptation.

Will natural selection account for closely correlated, or complex organs?

These wing-membranes—at least in what I believe to be their initial stage—are, as I have already remarked, themselves very simple organs, and also not in very close correlation with any other organs. But will natural selection account for changes in organs which are so closely correlated together that no variation in one of them can be of any use to the organism unless it is accompanied by corresponding variations in all the rest? And will it account for the complex perfection of an organ like the eye or the ear, consisting of many closely correlated parts?

Quotation from Herbert Spencer.

On this subject H. Spencer says:—"The co-operative parts must vary together, otherwise variation will be detrimental. A stronger muscle must have a stronger bone to resist its contractions; must have stronger correlated muscles and ligaments to secure the neighbouring articulations; must have larger blood-vessels to bring it supplies; must have a more massive nerve to bring it stimulus, and some extra development of a nervous centre to supply this extra stimulus. The question arises then,—does spontaneous variation occur simultaneously in all these co-operative parts? Have we any reason to think that they spontaneously increase or decrease together? The assumption that they do seems to me untenable."[2] He goes on to show that if, for instance, the horns of a deer grow larger through

[1] See especially the facts stated in the preceding chapter about respiratory organs, and those in the chapter on Comparative Morphology on the homological relations of the limbs of Vertebrates.

[2] Principles of Biology, p. 453.

spontaneous variation, and this, being advantageous to the deer by increasing its fighting power, is perpetuated by natural selection, it will be necessary for the muscles and bones of the neck and fore-legs to acquire increased strength in order to carry the increased weight of the horns; and it will be almost infinitely improbable that the necessary changes should all occur together from spontaneous variation only. But I agree with H. Spencer, that such cases present no difficulty whatever. Let natural selection increase the size of the horns, and self-adaptation will produce the corresponding increase of strength in the muscles and bones.

Complexities of the eye and the ear

But what are we to say of the complexities of the eye and the ear? We have seen that they cannot have been produced by self-adaptation. Neither the action of light on the eye, nor any action of the eye itself, can have any tendency whatever to produce the deposit of black pigment that absorbs the stray rays, nor to shape the transparent humours into lenses, nor to form the iris and its nervous connexions. And the hypothesis of natural selection appears equally inapplicable. In speaking of the flying squirrel, I have shown that I think natural selection adequate to account for any amount of improvement in a simple organ; but it does not follow that it will account for any improvement in a complex organ.

not due to natural selection.

H. Spencer's reasoning to show that the increase in the strength of an animal's neck and fore-legs at the very time when this is needed in order to carry heavier horns cannot be a result of mere spontaneous variation, applies, I think, with much greater force to so complex an organ as the eye.

Darwin on the simplest eyes.

"The simplest organ which can be called an eye consists of an optic nerve, surrounded by pigment cells, covered with translucent skin, but without any lens or other refractive body. We may, however, according to M. Jourdain, descend even a step lower, and find aggregations of pigment cells, apparently serving as an organ of vision, but which rest merely on sarcodic tissue not furnished with any nerve."[1] Darwin remarks "that, as some

[1] Darwin's Origin of Species, p. 216.

of the lowest organisms, in which nerves cannot be detected, are known to be sensitive to light, it does not appear improbable that certain elements in their tissues or sarcode should have become aggregated and developed into nerves endowed with special sensibility to its action."[1] This is in accordance with all that we know of the process of development; and I believe as firmly as Darwin can do that the eyes of the highest animals, like everything else in the organic creation, have been brought to their present perfection by adding together a number of small improvements, continued through an immense number of generations. But it does not follow that these improvements, even though almost infinitely small, can be due to natural selection among spontaneous variations. The higher the organization, whether of an entire organism or of a single organ, the greater is the number of the parts that co-operate, and the more perfect is their co-operation; and consequently, the more necessity there is for corresponding variations to take place in all the co-operating parts at once, and the more useless will be any variation whatever, unless it is accompanied by corresponding variations in the co-operating parts; while it is obvious that the greater the number of variations which are needed in order to effect an improvement, the less will be the probability of their all occurring at once. It is no reply to this to say, what is no doubt abstractly true, that whatever is possible becomes probable, if only time enough be allowed. There are improbabilities so great that the common sense of mankind treats them as impossibilities. It is not, for instance, in the strictest sense of the word, impossible that a poem or a mathematical proposition should be obtained by the process of shaking letters out of a box; but it is improbable to a degree that cannot be distinguished from impossibility; and the improbability of obtaining an improvement in an organ by means of several spontaneous variations all occurring together is an improbability of the same kind.[2] It is, of course, out of the question to find numerical data on such subjects, but the

Natural selection inapplicable to the highest organization.

Improbability equal to impossibility.

[1] Origin of Species, p. 215.

[2] See Note at end of chapter.

Algebraic statement.

reasoning admits of algebraic statement. If we suppose that any single variation occurs on the average once in m times, the probability of that variation occurring in any individual will be

$$\frac{1}{m};$$

and suppose that x variations must concur in order to make an improvement, then the probability of the necessary variations all occurring together will be

$$\frac{1}{m^x}.$$

Now suppose, what I think is a moderate supposition, that the value of m is 1000, and the value of x is 10 : then

$$\frac{1}{m^x} = \frac{1}{1000^{10}} = \frac{1}{10^{30}}.$$

To many readers these numbers will have no meaning. But it will speak to the understanding, though it will baffle the imagination, to say that if these suppositions are true, the probability against the concurrence of such variations as would constitute an improvement is expressed by a number which is about ten thousand times as great as the number of waves of light that have fallen on the earth since historical time began.[1] And it is to be further observed, that no improvement will give its possessor a *certainty* of surviving and leaving offspring, but only an *extra chance*, the value of which it is quite impossible to estimate.[2]

Of course this argument falls to the ground if it can be shown that it is not necessary for more than one variation to take place at the same time in order to constitute an improvement. But I think this is inconsistent with the unquestionable fact, on which I have already insisted, that in the highest organization there are both the greatest

[1] In 6,000 years there are, making no correction for leap years, $189{,}216 \times 10^6$ seconds. In one second there are 535×10^{12} undulations of yellow light. The product of these two numbers is $101{,}230{,}560 \times 10^{18}$, or not much more than 10^{26}, which is the ten-thousandth of 10^{30}.

[2] See Note at end of chapter.

number of co-operating parts, and the closest co-operation between the parts.[1] It is to be observed, that the foregoing argument is greatly understated. I have spoken only of the co-operation of parts in one organ. But in nature we have also to do with the co-operation of organs in one organism; and most organs are complex; so that there must be co-operation of many organs, each of them consisting of many parts. In some cases, no doubt, the principle of self-adaptation will account for one part becoming adapted to the rest, as we have seen in speaking of the deer's horns and the bat's wing-muscles; but this will not be always the case. What greatly increases the difficulty of supposing that the eye can have been formed by natural selection is, that it has been formed not on one, but on three distinct lines of descent. Well-developed eyes are found in the higher orders of Annulosa, Mollusca, and Vertebrata. We need not now discuss the question, whether these three groups are descended from a common ancestor; if they are, that ancestor must have been, in all probability, of too low an organization to have eyes. We may infer this from the facts that the lowest known vertebrate, the amphioxus, has only rudimentary eyes,[2] and the lower Mollusca and Annulosa have none. The eye must consequently have been separately perfected in those three groups. It is a fact of the same class, that the Cephalopoda (cuttle-fish and nautilus), which are the highest of the Mollusca, resemble the Vertebrata not only in the general higher development of the nervous system and of the eyes, but in the special and very remarkable

Co-operation of parts in an organ, and of organs in an organism.

The eye has been formed on three separate lines of descent.

Skulls of Cephalopoda and of Vertebrata.

[1] H. Spencer has given the emphasis to this argument that it deserves (see the extract above). Yet he says, though without offering any proof, that the complexities of the sensory organs must be the result of natural selection. I cannot avoid thinking that he has been biassed by a determination to assign a *physical* cause, such as either self-adaptation or natural selection, for all biological facts, to the exclusion of intelligence. (See his Principles of Biology, vol. ii. p. 307.)

[2] "An eye, such as exists in the fish called the lancelet (amphioxus), which is so simple that it consists only of a fold-like sac of skin, lined with pigment and furnished with a nerve, but destitute of any other apparatus, being merely covered by transparent membrane." (Darwin's Origin of Species, p. 218.)

character of having a skull formed of cartilaginous plates, to protect the cephalic ganglia; and yet there is no true affinity between the Cephalopoda and the Vertebrata, by the test either of morphological anatomy, or of development, or of a gradation of intermediate forms: so that the skulls of the two groups, like their eyes, must have been formed separately. Exactly the same remarks will apply to the fact, that both the Vertebrata and the higher Annulosa have their voluntary muscles formed of striated fibre, while the involuntary muscles of those groups, and all the muscles of the Mollusca, are non-striated.[1] If the Vertebrata and the Annulosa have been descended from a common ancestor, that ancestor must have been far too low in the scale to possess striated muscle; and consequently that tissue must have been formed in those two groups independently. The origin of tissue, however, is so totally unknown, that no argument drawn from it can be of much weight. I have already admitted that I do not see any absurdity in the idea of the muscular, and perhaps even the nervous tissues being, in some way, originally produced by a process of self-adaptation.

Striated muscular fibre in Annulosa and in Vertebrata.

Spontaneous variation and natural selection is a process of blind trial,

Natural selection among spontaneous variations may be described, without a metaphor, as a process of experiment by mere *blind trial*, and preserving the results of the successful experiments, while the failures are destroyed and forgotten. I do not deny that great results have been obtained in this way. Such has been the case in some chemical arts; above all, I believe, in photography; and it is by such a process of blind experimenting, without any acoustic theory to guide the experiments, that musical instruments have attained to their present high degree of perfection. But this method is applicable only to cases where the process of experimenting is comparatively simple. Were it necessary for ten different experiments at once to be successful, in order that any result at all might be obtained, such a method would be totally inapplicable; the improbability of success would be an improbability of

and inapplicable to complex conditions.

[1] Carpenter's Comparative Physiology, p. 442.

the same kind (to recur to a former illustration) as that of obtaining a poem by shaking letters at random out of a box.

Summary.

I conclude from these facts and reasonings, that the facts of organization may be accounted for in part by the direct action of external inorganic forces on the organism; in part by the action of the organism itself, producing self-adaptation; and in part by natural selection among spontaneous variations: but that in addition to, and in co-operation with, all these, there must be a principle of Organizing Intelligence. I shall defer the further consideration of the bearings of this conclusion to a future chapter, and shall end this with some observations on that very remarkable class of adaptations known as Imitative Resemblances.

Imitative colouring

Many birds, insects, and other animals have colours resembling those of the objects among which they live. The purpose of this, beyond doubt, is protection against enemies: but what is the cause? Natural selection is the most obvious cause to assign, and in many cases it is probably quite adequate:—those individuals which were coloured like the objects among which they lived, escaped their enemies oftener than the ones not so favoured, and consequently survived and bequeathed their colouring. This view is supported by the fact that imitative colouring is worn by no birds except those which inhabit exposed places, where they would be in danger from birds of prey.[1] But this cannot be the purpose of the white colour of the Polar bear, which has no enemies, at least on land; its white clothing must have been given to it for warmth, as white substances are those which radiate heat the slowest. Natural selection, however, will apply equally well to this case; and if all cases of adaptive colouring were *single*, I should think this explanation would account for them all. But they are not all single; there is the remarkable double fact of some animals, of which the ermine is the best-known

in birds, | in the Polar bear, | and in the ermine.

[1] This is stated by the Duke of Argyll in "The Reign of Law."

instance, having a white covering in the winter, and one of another colour in the summer. I cannot think that this is a result of natural selection among spontaneous variations, because I cannot think that it could ever arise as a spontaneous variation; I think it must be in some way due, fanciful as the notion may appear, to an action of the light reflected on the animal from the surfaces among which it lives. The same is perhaps true (though this is a very large concession to those who refer all the facts of organization to the action of inorganic forces)—the same, I say, is perhaps true of the wonderful power possessed by the chameleon and a few other animals, of assuming a colour similar to that of the neighbouring surface, whatever that may chance to be. These, in my view, can scarcely be regarded as cases of *self*-adaptation: they belong rather to the class of adaptations produced by the direct action of external inorganic forces.

The chameleon.

Mimicry.

But the fact of *mimicry*, as distinct from mere imitative colouring, can, I think, be accounted for by natural selection, and by natural selection only. Mr. Bates, the author of "The Naturalist on the Amazons," has shown "that in a district where, for instance, an ithomia abounds in gaudy swarms, another butterfly, namely a leptalis, will often be found mingled in the same flock, so like the ithomia in every shade and stripe of colour, and even in the shape of its wings, that Mr. Bates, with his eyes sharpened by collecting during eleven years, was, though always on his guard, continually deceived. When the mockers and the mocked are caught and compared, they are found to be totally different in essential structure, and to belong not only to distinct genera, but often to distinct families. If this mimicry had occurred in only one or two instances, it might have been passed over as a strange coincidence. But travel a hundred miles, more or less, from a district where one leptalis imitates one ithomia, and a distinct mocker and mocked, equally close in their resemblance, will be found. Altogether no less than ten genera are enumerated, which include species that imitate other butterflies. The mockers and mocked always inhabit the

Quotation from Darwin.

Mr. Bates on mimicry among butterflies.

same region ; we never find an imitator living remote from the form which it counterfeits. The mockers are almost invariably rare insects ; the mocked in almost every case abound in swarms. In the same district in which a species of leptalis closely imitates an ithomia, there are sometimes other lepidoptera mimicking the same ithomia ; so that in the same place, species of three genera of butterflies and even moths may be found, all closely resembling a species of a fourth genus. It deserves especial notice, that many of the mimicking forms of the leptalis, as well as of the mimicked forms, can be shown, by a graduated series, to be merely varieties of the same species ; whilst others are undoubtedly distinct species. But why, it may be asked, are certain forms treated as the mimicked, and the others as the mimickers ? Mr. Bates satisfactorily answers this question, by showing that the form which is imitated keeps the usual dress of the group to which it belongs, whilst the counterfeiters have changed their dress, and do not resemble their nearest allies."[1]

Its purpose is protection.

The purpose of mimicry is the protection of the mimickers. The species which they mimic, probably in consequence of some odour that they emit, are not preyed on by birds ; and of course it is a protection to the butterflies which do not emit any such odour, to be mistaken for those which do. The mimicking forms have no doubt been produced by the survival, through successive generations, of those individuals belonging to defenceless species, which most nearly resembled the kinds that have natural means of protection. For the same reason, insects that sting are never known to mimic others, though others sometimes mimic them.[2]

Its cause is natural selection.

[1] Darwin's Origin of Species, p. 503.

[2] Ibid. p. 506.

NOTE.

FORMATION OF COMPLEX ORGANS.

Grey-hound.

IN answer to the objection that selection is inadequate to produce a co-ordinated structure of many parts, Darwin[1] points to the instance of the greyhound, all the parts of which are together "adapted for extreme fleetness, and the running down of weak prey;" yet the greyhound has been formed by selection; and the most competent selectors do not attempt to obtain all kinds of excellence at once, but try for one point at a time.[2] This instance is conclusive as to the correlation of characters, each of which may vary a little without necessitating variation in the rest. But I do not think it will apply to such an organ as the eye. On this subject Darwin says:[3]—

"A writer has recently maintained that 'it is probably no exaggeration to suppose that, in order to improve such an organ as the eye at all, it must be improved in ten different ways at once. And the improbability of any complex organ being improved and brought to perfection in any such way, is an improbability of the same kind and degree as that of producing a poem or a mathematical demonstration by throwing letters at random on a table.'[4] If the eye were to be abruptly and

1 Variation under Domestication, vol. ii. p. 221.

2 "The excellence of one sub-variety (of pigeon), the Almond Tumbler, lies in the plumage, carriage, head, beak, and eye; but it is too presumptuous in the beginner to try for all these points." The great judge above quoted (J. M. Eaton) says:—"There are some young fanciers who are over-covetous, and go for all the above five properties at once: they have their reward by getting nothing." (Variation under Domestication, vol. ii. p. 198.) Though these remarks are quoted of pigeons, Darwin evidently means them to apply to the improvement of the breeds of all animals. Compare what he says in p. 221: "From what we know of the method which different men follow in improving their stock—some chiefly attending to one point, others to another point, others again correcting defects by crosses, and so forth."

3 Variation under Domestication, vol. ii. p. 222.

4 Darwin here quotes from my opening address to the Belfast Natural History Society, reported in the *Northern Whig*, Nov. 19, 1866.

greatly modified, no doubt many parts would have to be simultaneously altered, in order that the organ should remain serviceable. But is this the case with smaller changes?" He then speaks of the changes that would be needed in order to adapt the eye of a diurnal species for a nocturnal life—a case which presents no great difficulty; and afterwards says:—"Amphibious animals, which are enabled to see both in the water and in the air, require and possess, as M. Plateau has shown, eyes constructed on the following plan: 'The cornea is always flat, or at least much flattened in front of the crystalline and over a space equal to the diameter of that lens,[1] while the lateral portions may be much curved.' The crystalline is very nearly a sphere, and the humours have nearly the same density as water. Now, as a terrestrial animal became more and more aquatic in its habits, very slight changes, first in the curvature of the cornea or crystalline, and then in the density of the humours, or conversely, might successively occur, and would be advantageous to the animal whilst under water, without serious detriment to its power of vision in the air."

Eyes of amphibious animals.

I confess I do not see much force in this argument. The subject is most intricate, but I know of no reason for thinking it possible that any apparatus consisting of lenses can be improved by any method whatever, unless the alterations in the density and the curvature are perfectly simultaneous; and the probability against this taking place by mere spontaneous variation is practically infinite.

[1] The purpose of the flat cornea is evidently to produce as little difference as possible in the way in which the rays of light enter the eye from air and from water.

CHAPTER XXV.

GENERAL REMARKS ON THE DEVELOPMENT OF SPECIES.

Origin of life in Creative Power.

IN giving a brief summary of the argument on the origin of species, it is best to begin by repeating, that the origin of life is a distinct question. We have every reason to believe that life, like matter, has had its origin in the direct action of Creative Power. Accepting, then, the facts of life, with the laws of habit and variation, as primary data, the question is, how particular organic *structures*, and particular organic *species*, have come into existence.

Only two theories are possible as to the origin of species: separate creations, or development.

Let us take the question of the origin of species first, as indeed it includes the other. Only two answers to this question appear to be possible. Either every species (with of course great indefiniteness as to the question what are in point of fact real and distinct species),—either every species, I say, has been separately created, or all species, both animal and vegetable, have been derived, by descent with modification, from one, or at most a few, germs that were originally vitalized by Creative Power. So long as the world was believed to be only a few days older than man, the theory of separate creations was necessarily accepted. But when geological time was found to be indefinitely long, and when geology further disclosed the fact of a succession of species, the one set displacing the other and succeeding to it throughout geological time, the question of the possibility of a change of species through descent was immediately raised. Such an hypothesis is no doubt surrounded with difficulties; or, it would be more correct to say, such an hypothesis raises a vast number of questions, most of which are not yet solved, and may pro-

Question raised by geological discovery.

Difficulties of development theory partly are probably insoluble,

bably remain ever unsolved. But all that we have learned, of the variability of form and function in organisms, tends to diminish the difficulties of this hypothesis; while all that we have learned concerning the facts of development, embryology, morphology, and classification, tends to increase its probability; and that probability is, as I think, raised to the rank of a certainty by the discovery of rudimentary and useless structures, both in mature and in embryonic forms.

but they lessen with the advance of knowledge.

It appears to be a prevalent notion, that, whatever may be hereafter concluded on as true, the presumption is at present in favour of the theory of separate creations, and will continue to be so until the argument is closed. I cannot admit this; I think that it has no logical foundation whatever, and that it owes the force it has in men's minds merely to the theory of separate creations being familiar; while the theory of the origin of species by descent with modification (or, briefly, the development theory) is still comparatively strange. It is not to be hoped that the difficulties of the development theory can be cleared up at once, or that they can be fully cleared up at all. The evidence is too scanty, and the experimental method, which has created the sciences of physics and chemistry, is scarcely applicable here. But the ordinary objections to the development theory are utterly futile. It is said that we have never seen a new species come into existence by descent. This is scarcely true, for many races of plants and animals have come into existence under domestication, which it is nearly if not quite impossible to distinguish from true species.[1] But it is quite true that we have never seen any such change as the descent of a bird from a reptile would be; and yet the birds and the reptiles are both vertebrates, and must, therefore, on the development theory, be descended either the one class from the other, or both from a common origin. It is true, I say, that such a change is quite out of our experience; but the separate and special creation of any organic form out of dust, or out of nothing, is equally outside of our experience, and far

No presumption against the development theory.

Arguments from experience against it

are worthless.

[1] See Note at end of chapter.

more remote from it; for we have experience of the origin of races by descent with modifications, though very small modifications, but we have no experience at all of the origin of a race by special creation. I believe this kind of argument from direct experience, in the narrowest sense of the word experience, is good for very little; but, such as it is, it is in favour of the development theory, and not against it.

The argument from experience is in its favour.

Difficulties about man.

This is the place for referring to those difficulties of the development theory which appear to be keenly felt by many, in connexion with the origin of man.

Development theory applicable to man.

Man is developed, like all other organisms, out of a minute structureless germ, which cannot by itself be distinguished from that which will develop into the form of any other species. Man is an air-breathing Vertebrate; I have brought forward what I believe to be conclusive proofs that all air-breathing Vertebrates have been descended from fishes; and if these arguments are good for other species, they are good for man also. Man is closely allied in his physical structure to the apes; the best authorities appear to be agreed with Professor Huxley, that there is no difference, either in the brain or in any other part of the body, between man and the apes that can be regarded as in any way fundamental. The superiority of man's mental powers to those of the highest animal is no doubt so great that it may be regarded as infinite; but we have seen that motor and mental characters are so variable in comparison with formative ones, that they are no index whatever to the affinities of a species. As a question of biological science, consequently, I see no reason to doubt that man, like other species, has been developed out of lower forms.

Man's brain not essentially unlike the ape's.

The repugnance to this belief rests on the notion that where there is gradual change there can be no fundamental change of nature; and, consequently, that if man has been developed out of an ape, he is still essentially an ape. Now, without entering on any logical or metaphysical discussion, I meet this argument by saying that such is not the fact: I say that a gradual change by development may be a fundamental change. The logical, or meta-

physical, difficulty of conceiving how such a being as man can be descended from an ape, the ape from a fish, and the fish from a Protozoon, is paralleled in the life of every human being, by the facts that the child, before it learns to speak, appears to have no higher mental nature than that of a dog; that for some considerable time after birth it appears to have no mental nature at all; and that at the first moment of its conception it is not only without mental nature, but without any higher organic nature than that of a Protozoon. The development of the individual is in the highest degree mysterious; but the mystery is only repeated, and the difficulty is not increased, if it is true, as I believe it is, that the development of the individual, from the structureless germ up to the man, has had its parallel in the development of the race. The relation of man's spiritual nature to his animal nature is, no doubt, one of the greatest of all mysteries; but the relation of life to matter is equally mysterious, though it is a lower kind of mystery. No merely physical science can elucidate a spiritual mystery like this; but, in my opinion, the discovery that man's brain has no anatomical superiority to that of the highest apes, from which his mental superiority could possibly be guessed, is so far from lending support to a materialistic view of our spiritual nature, that it tends to cut away the ground from under any materialistic argument. I do not see any improbability in the belief that the same Creative Power which at the beginning created matter, and afterwards gave it life, finally, when the action of that life had developed the bodily frame and the instinctive mental powers of man, completed the work by breathing into man a breath of higher and spiritual life.

The development of man from the lowest forms is paralleled in the life of every individual.

Man's spiritual nature may be a direct result of Creative Power.

The theory, or rather the law, of organic types has been sometimes set up in opposition to the theory of development. The notion of any opposition between them, however, is a pure misconception. By the law of types is meant the fact, which has been stated at greater length in the chapter on Morphology, that homologous parts are found through vast numbers of species—as, for instance,

The law of organic types

through the whole vertebrate group; and that when a new organ is needed—as, for instance, a wing instead of a leg—the type is not radically altered, but modified in such a way as to leave the same anatomical elements still discernible. There are some who regard it as a sufficient answer to the question of the origin of species, to say that the Creator has laid down plans, or types, for the Vertebrata, and for each of the other great groups, and then modified the vertebrate type to suit the special modes of life of the fish, the quadruped, and the bird; and the other types in the same way. Now, as a statement of fact, this is perfectly true; but it is only a generalized statement of fact—it is no explanation. The development theory takes up the question at this point, admits the law of types as true, and shows why it is true; namely, that homological resemblances are due to community of descent. The development theory does for the multitudinous facts of morphology, embryology, and classification, what Kepler's laws did for the mass of facts previously known concerning the planetary motions: it shows how they are to be referred to simple and intelligible principles. But Kepler's laws left unanswered the question of the agency by which the planetary motions were determined; and the development theory, considered merely as such, leaves unanswered the question by what agency the development of species has been produced. Any theory that will explain this will do for the development theory what the Newtonian theory of gravitation has done for Kepler's laws. Darwin believes that he has discovered such a theory. I regard his theory as not false, but totally insufficient; partly because, as I have shown at some length in the last chapter, I do not believe it will in any degree explain the more complex facts of organization; partly because, while it throws very great light on the variation of *forms*, it throws little or none on the origin and variation of *tissues*.

explained by the theory of development.

The development theory does not answer the question of the cause of development.

I have not yet considered the geological evidence on the subject of the origin and succession of organic forms. I

believe the geological evidence is too scanty and fragmentary to be of much value;[1] but what we have is certainly favourable to the belief that there has been, on the whole, an advance in grade of organization during geological time. Thus, reptiles have been superseded, to a great extent, by warm-blooded animals; the great marine reptiles have given place to whales and other Cetaceans, the great land reptiles to Mammalia, and the Pterodactyles, or flying reptiles, to birds. This, however, says nothing either for or against the theory of natural selection among spontaneous variations as the principal cause of improvement. But I think that, on the whole, geological evidence is against that theory. Were it true—were natural selection not only one cause of change, which it certainly is, but the principal cause—improvement ought to take place most rapidly in the classes where there is most variability, and least fixity of form: in other words, selection ought to do most where there are the most numerous and the greatest variations to select from. Now, variability as between individuals is greatest in the lowest classes: but this does not cause the production of new species to go on among them with any corresponding rapidity. Geologists, on the contrary, appear to be agreed that old species disappear, and new ones come to take their places, most rapidly in the highest classes. I think this is an important argument in favour of believing that advance in development is due to some vital power which is most energetic in the highest classes, and not to any mere inorganic agency like natural selection.

Geological evidence favours the belief in advance. Reptiles have given way to warm-blooded animals.

Geological argument against Darwin's theory.

Improvement goes on most rapidly in the highest classes.

We have to account not only for the fact of improvement, or, in other words, for advance in grade of organization, but for the fact that improvement goes on in divergent lines. The organic tree not only grows higher, but branches out into classes. This, however, presents no difficulty, if it is admitted, as the development theory requires, that if

Divergence of character.

[1] See the chapter, in Darwin's Origin of Species, on the Imperfection of the Geological Record; also "Illogical Geology," in the second volume of Herbert Spencer's Essays.

time enough is allowed variation is perfectly indefinite in amount, at least within the limits of the same fundamental form. Isolation alone appears to produce change. If a small colony of any species whatever were to be isolated from its kind, it can scarcely be doubted that after some generations it would come to constitute a distinct variety. Such cases have occurred under domestication;[1] and they must have been of constant occurrence in nature whenever some of the individuals of a species have been isolated from the rest by the formation of mountain or sea barriers.

Effect of isolation in producing change.

But it is on the largest areas obviously that there will be the largest number of chances of favourable variations occurring; and there consequently those species will be perfected which will be most successful in the "struggle for existence."[2] Thus European and Asiatic species of plants are now overspreading Australia and New Zealand, while the Australian and New Zealand species, which have been introduced as garden plants, have little tendency to become wild in Europe. No doubt the most favourable state of things for the promotion of variation and advancement is that which geological conditions have produced,—constant, but generally slow changes in the conditions of life; general severe competition, with many isolated areas in which it is less intense; colonies frequently shut off from the parent stock, and left alone to vary or to remain unchanged; and species which had been matured in separate regions suddenly brought into competition by the removal of barriers. Every geological change will tend to

The largest areas produce the most dominant species.

General effect of geological conditions.

[1] "Youatt gives an excellent illustration of the effects of a course of selection, which may be considered as unconsciously followed, in so far that the breeders could never have expected, or even have wished, to produce the result which ensued—namely, the production of two distinct strains. The two flocks of Leicester sheep kept by Mr. Buckley and Mr. Burgess, as Mr. Youatt remarks, 'have been purely bred from the original stock of Mr. Bakewell for upwards of fifty years. There is not a suspicion existing in the mind of any one at all acquainted with the subject, that the owner of either of them has deviated in any one instance from the pure blood of Mr. Bakewell's flock, and yet the difference between the sheep possessed by these two gentlemen is so great, that they have the appearance of being quite different varieties.'" (Darwin's Origin of Species, p. 37.)

[2] Ibid. p. 119.

promote change of the living species in different ways: by causing self-adaptation to the new conditions of life; by directly stimulating variation, and by selecting those variations which are best adapted to the new conditions. What I wish now to insist on is, that all this will necessarily produce "divergence of character;" for the new influences will most probably act on only part of the individuals of a species, and among those which do come under the new influences it is probable that different variations will be adapted to different habits of life, and will be formed by hereditary habit and natural selection into permanent varieties or new species. Thus the constant tendency of change will be to produce new varieties; and it appears impossible that any retrograde change can reverse this, or that it can be undone by any cause except their extinction.

Tendency of geological changes to constantly greater variation.

It is to be remembered also that with any particular variation other variations will probably be correlated; but of the laws of such correlations we know nothing.

Correlation of variations.

It can scarcely be doubted that the lowest organisms are the most plastic, and consequently the most capable of assuming organization of a new type. It is probably for this reason that allied groups, as already remarked, are generally united by their lowest, and not by their highest members. In more technical language, the least differentiated species have the greatest capacity for further differentiation, and are capable of giving origin to widely distinct groups above them. Thus, for instance, the lowest air-breathing Vertebrates—the Batrachians—are allied not with the highest, but with some of the lowest fishes. The lowest fishes, on the development theory, have given origin to the higher fishes on the one side, and to the air-breathing Vertebrates on the other. But we cannot assert that this is universally the case. The affinities of birds, I believe, are rather with the higher than with the lower reptiles; and the same is probably true of the mammalia.

Lowest organisms are most plastic.

Classes are usually united by their lowest members.

There may be exceptions to this.

Any intelligent man who has taken the trouble of following my reasoning so far will very probably make these

Apparent inconsistencies of

my argument.

two remarks—that I have first rejected natural selection among spontaneous variations as a complete theory of the origin of species, and afterwards gone on as if I thought it true; and that I treat intelligence as a *Deus ex machinâ*, explaining vital phenomena, so far as I can, by merely physical causation, referring them to the action of external agents, self-adaptation, and natural selection, and only calling intelligence in as a solution when the physical causes fail to account for the facts.

Life does not supersede, but works through, the properties of matter:

so intelligence with unintelligent forces.

These relations are inexplicable.

We have mental experience of the action of intelligence.

I shall reply to these two objections together. I believe, as I have more than once stated already (and I think I here state the universal belief of scientific men)—I believe, I say, that the action of life does not supersede the ordinary physical laws of causation—or, in other words, does not supersede the ordinary properties of matter—but that life produces its results of organization by guiding the action of causation, and by working through the ordinary properties of matter. So it is with intelligence. As life works through the inorganic forces, so intelligence, I believe, works through the unintelligent forces. All the inorganic forces are unintelligent, and so, I believe, are the laws of habit and variation. The relation of life to the inorganic forces is totally inexplicable, and the relation of intelligence to the unintelligent forces is equally so; but the latter, though inexplicable, forms part of our mental experience. Our mental life is partly intelligent and partly merely habitual. The intelligent and voluntary powers of the mind, as I shall have to show in a future chapter, do not supersede the action of the habitual powers, but work through them; and it is, I believe, the same in our unconscious or bodily life. Self-adaptation takes place according to the laws of habit, and according to that remarkable physical law in virtue of which every part that has increased work thrown on it within the limits of what is good for its health, increases in size, in strength, and in general efficiency; but it appears to be universally admitted that there are many adaptations for which no mere blind habitual process of self-adaptation will account. Natural selection also is a

purely physical process, a case of purely physical causation; but I have given reasons, which to my mind are conclusive, against accepting natural selection as an explanation of the complexities of organic structure. But I believe that these physical agencies, self-adaptation and natural selection, are what produce organization, and are the operative causes of progress in organization; not, however, acting alone, but under the guidance of intelligence. I believe that intelligence guides the process of self-adaptation, producing adaptations which no unintelligent process could produce. I have no doubt the law of natural selection is universally operative, in this sense, that natural selection by "survival of the fittest"[1] in the struggle for existence is the reason why new and improved races, *when once formed*, supersede the old and unimproved ones; but I have stated my reasons for believing that spontaneous variation alone can never produce any complex organization. I believe that intelligence determines those variations to occur together which are needed together. To return to a former instance:—If I am right, such an organ as the eye has been formed by a series of gradual successive improvements, in each of which those different variations in the different parts of its complex structure which are necessary to make one another useful have been determined to occur together by the mysterious power of unconscious organic intelligence. But every improvement, when once made, has been preserved, perpetuated, and multiplied by the action of natural selection.

Self-adaptation is guided by intelligence.

Intelligence determines co-operating variations to occur together.

I believe that organizing intelligence co-exists and co-operates with the unintelligent forces through all life; but that intelligence is most completely dominant in the highest life. It is where intelligence is most completely dominant that, as we have seen, organic progress is most rapid; though there is least spontaneous variation among the most highly organized forms, and consequently it is among them that the least could be done by mere natural selection among unguided spontaneous variations.[2] And it is

Intelligence is most dominant in the highest life.

[1] This expression is used in Spencer's Principles of Biology.

[2] See p. 333.

also where intelligence is most completely dominant that we find those organs, such as the eye and the ear, of which the purpose is the most evident and the most definite, and which appear most completely beyond the power of any merely physical causation to construct. Purpose, as I remarked early in this work, is most traceable where cause is least so.

In the first chapter of the second volume I shall have to consider what this organizing intelligence is; and this will further open the question of the relation between the unconscious life and the mind.

NOTE A.

THE OPERATION OF NATURAL SELECTION.

Why does natural selection preserve the highest?

THE first question of an intelligent man when he first hears the theory of the Origin of Species by means of natural selection among spontaneous variations, will very probably be something like this:—Granting its postulates, your theory no doubt accounts for the origin of *different* species, one from the other, by descent. But the most important and conspicuous fact in comparing species and classes is not mere variation, but advance. Granting that natural selection among spontaneous variations is *adequate* to effect the transition from the Protozoa up to the highest warm-blooded animals, the question still remains, why the changes it effects are in this direction? Why does natural selection, or "survival of the fittest," on the average and on the whole, preserve those variations that constitute advance in organization, and destroy the retrograde ones?

Because the highest are most efficient.

The answer to this is obvious, and is contained in what has been said already. The most highly organized beings have an advantage over others in the struggle for existence. Strength of muscle, perfection of the organs of motion and prehension, acuteness of the nerves of sense, perfection of the eye and ear, and increased development of the nervous centres producing mental intelligence,—all these constitute advance in grade of organization, and all at the same time give their possessor an

increase of power to fight the battle of life, and consequently an increased chance of surviving and leaving offspring. This, however, is only an average result, not a uniform or constant one. For instance, if an animal becomes internally or externally parasitic on other animals, it will have little or no occasion for acute senses or great motor power; its organs of sense and motion will consequently degenerate, and the whole organism, taken altogether, will undergo a retrograde change; while the great facility of obtaining abundant nourishment which its parasitic life affords, will cause the variation to be a favourable one, and it will be perpetuated. Such has no doubt been the origin of the "suctorial parasites" on fishes and whales, into which many freely swimming crustacean larvæ are metamorphosed. But such cases are distinctly exceptional. As a rule, natural selection will preserve only those variations which constitute an advance in organization, and the rest will perish.

Exceptions.

Retrograde change.

Suctorial parasites.

Here another question arises, which Darwin has not seen, but which H. Spencer has seen and satisfactorily answered.[1] The ability of an individual, or of a species, to survive in the battle of life no doubt depends on its organization; and the chances are, on the whole, in favour of the highest organization. But the probability of its not only surviving but leaving offspring, does not depend on this exclusively; it depends partly on its organization, but partly on its fecundity. Other things being equal, the highest organization will have the best chance. But, other things being equal, the greatest fecundity will have the best chance. The chance that any variety will have of being preserved by natural selection will be in a ratio compounded of its organization and its fecundity.

Chance of leaving offspring partly determined by fecundity.

The advantage that fecundity gives to a species may be seen by comparing the rabbit with the hare. The hare would probably be by this time extinct in the cultivated parts of our country, were it not preserved, while the rabbit has no difficulty in maintaining its position; a difference which may be partly due to the burrowing habits of the latter, but much more, I think, to its great fecundity.

Rabbit and hare.

To resume the argument. Fecundity and high organization do not in general accompany each other, but the reverse. The

High organiza-

[1] What follows is in substance taken from Spencer's Principles of Biology, Part VI., especially chapters ix. and xi. The algebraic statement of the reasoning is my own.

tion and fecundity are opposed.

highest organisms have on the whole the least fecundity. Compare the comparatively small number of young produced by birds and Mammalia with the thousands of eggs produced by some fishes and many insects, and the countless germs of the lowest animals and plants. Might it not be expected, that whatever is gained in the chance of leaving offspring by advanced organization will on the average be lost by diminished fecundity; that the greater fecundity of the inferior types will give them as good a chance of leaving offspring as the superior ones; and that the superior and the inferior species will thus be in the long run evenly matched in the battle of life, giving the superior ones no permanent advantage?

Bearing of this law on natural selection.

This would be so if all other things were equal. But all other things do not remain equal. The advantage of any favourable variation to a race consists generally either in greater facility of obtaining food, or in greater facility of escaping enemies; and either abundant food or tranquillity of life will tend to increase fecundity. So that advance in grade of organization, though it will entail diminished fecundity as its direct effect, will tend to counteract this effect in an indirect way, namely by placing the organism in external circumstances favourable to its fecundity.

In such a question, verification by observation or experiment is totally out of the question. But the above reasoning, considered merely as reasoning from what data we have, is, I think, sound and satisfactory. It may be well to put it into an algebraic form.

Algebraic statement.

Call grade of organization x, and fecundity y. Suppose, what is approximately true, that the chance of surviving and leaving offspring is proportionate to their product xy; and suppose, what is also approximately true, that, other things being equal, the values of x and y are inversely as each other; then, other things being equal, xy will be a constant quantity, and no increase in the value of x from any favourable variation will increase the chance of leaving offspring. Call now abundance of nutrition a. Within limits, the value of y, as already shown, will increase with that of a, and the value of a will increase with that of x; so that any increase of the value of x from spontaneous variation will tend to increase that of y, and consequently of the product xy; while, on the contrary, no increase of the value of y will have any tendency to increase that of either x or xy.

NOTE B.

At the time when the foregoing chapter was written, I was not aware of the fact mentioned by Mr. Lewes in an article on Darwin's theory in the *Fortnightly Review*, that the domestic and the wild Guinea pig are not fertile together. Mutual fertility is the usually accepted test of identity of species; so that by this test these two are distinct species.

The domestic and wild Guinea-pig do not breed together.

CHAPTER XXVI.

THE RATE OF VARIATION.

Variation is slow:

IT is a necessary result of any form of the development theory, indeed I may say a part of it, that the process of variation by which any great change in organic forms has been effected has been extremely slow: so slow as to be measurable only by geological time. Darwin constantly insists on this.

Of course it is impossible to doubt that such a change as that involved in the descent of warm-blooded animals from fishes, or of winged insects from worms, must have occupied immeasurably long geological ages. But Darwin goes much further than this; he thinks that all species whatever have been formed by a process of variation not more rapid than that by which, in most cases, our domestic races have been, and are, improved. I am inclined here to differ from Darwin. I think it most likely that, in many cases, species have been formed at once by considerable variations; variations not comparable to that which would be necessary to derive an air-breathing animal from a water-breathing one, but amounting to the sudden formation of new species and new genera.

but I think not so slow as Darwin maintains.

Possible sudden origin of new species.

Such has occurred under domestication.

In this belief there is nothing inconsistent with the laws of life. Variations, equal in magnitude to the production of new species, do occur under domestication. I have mentioned, in the chapter on the Laws of Variation, a case of a new variety of the poppy appearing suddenly, which had "a remarkable variation in its fruit, a crown of secondary capsules being added to the normal central capsule:" and a similar case of the datura tatula, present-

Poppy.

Datura tatula.

ing a variety with smooth fruit instead of spinous.[1] Here are two cases of variations amounting to specific differences, which appeared suddenly, and were propagated by seed: they are in fact cases of the production of new species, not by gradual, but by sudden variation, and they would be recognised as such if they had appeared in the wild state. The otter, or Ancon, sheep of North America was also the result of a sudden variation; and the difference in the form of its skeleton from that of the common sheep amounted to a specific if not a generic difference. Thus we see that sudden as well as gradual variation may give rise to what are really new species, both of plants and animals. It is true, these instances, and others that could be mentioned,[2] have arisen under domestication; but why may not the same have taken place in the wild state? Darwin thinks they do not: "Various general reasons," he says, "could be assigned against such a belief: for instance, without separation a single monstrous variation would almost certainly be soon obliterated by crossing."[3] I think this difficulty is quite imaginary. We know that vegetable species and varieties usually propagate their kind truly; and among animals, once a race has been formed, the instinct of every race to unite with its own kind will, in the wild state, prevent crossing. Besides, even if they unite, it is by no means certain that their union would produce a mixed race, having characters intermediate between the two parent stocks. When two slightly different individuals unite, the offspring, no doubt, have on the average an intermediate character; and thus it is that where free intercrossing is permitted, separate breeds do not usually arise in the same country. But this is not always the case when the union is between individuals of very unlike races. "When the Ancons (or

Ancon sheep.

Instinct will prevent crossing.

Crossing might not produce a mixed race.

[1] P. 197.

[2] "It is certain that the Ancon and Manchamp breeds of sheep, and almost certain that the niata cattle, turnspit and pug dogs, jumper and frizzled fowls, short-faced tumbler pigeons, hook-billed ducks, &c. and with plants a multitude of varieties, suddenly appeared in nearly the same state as we now see them." (Darwin's Variation under Domestication, vol. ii. p. 414.)

[3] Ibid.

otter sheep) are crossed with other breeds, the offspring, with rare exceptions, perfectly resemble either parent."[1] For these reasons, I think there is no improbability in sudden, as well as slow, variations occurring among organisms in the wild state; though, as wild organisms are much less variable than domestic ones, they must occur much more rarely.[2] It may be true that we have no evidence of the origin of wild species in this way. But this is not a case in which negative evidence proves any-thing. We have never witnessed the origin of a wild species by any process whatever; and if a species were to come suddenly into being in the wild state, as the Ancon sheep did under domestication, how could we ascertain the fact? If the first of a newly-begotten species were found, the fact of its discovery would tell nothing about its origin. Naturalists would register it as a very rare species, having been only once met with, but they would have no means of knowing whether it were the first or the last of its race.

Sudden origin of a wild race would not be discovered.

Geological time too short for the theory of *slow* variation.

I consequently think that sudden variation is not only possible, but probable. And I further doubt whether the development theory is tenable unless we admit it. I am inclined to think that geological time is too short for the evolution of the higher forms of life out of the lower by that accumulation of imperceptibly slow variations, to which alone Darwin ascribes the whole process.

This will surprise many readers. It is almost as startling now to be told that geological time is less than infinite, as it would have been a hundred years ago to be told that historical time was but a small fraction of the age of the earth. Nevertheless, the reasoning which has been briefly stated in the chapter on "the Motive Powers of the Universe," proves that the order of things on the earth must have had a beginning; and Sir William Thomson has roughly estimated the past duration of the solar system in its present state at about five hundred millions

Age of the earth according to Sir W. Thomson.

[1] Darwin's Variation under Domestication, vol. i. p. 100.

[2] "Sports" are extremely rare under nature, but far from rare under domestication. (Darwin's Origin of Species, p. 10.)

of years; previous to which time it was condensing out of its original nebula. Of course this calculation does not make the slightest pretension to precision, but all that is needed for the present argument is the order of the magnitude.[1] Five hundred millions of years is a period so overpowering to the imagination, that it is no wonder if most readers think it equivalent for all practical purposes to eternity. I think, however, that for the present purpose this is very doubtful.

The greyhound an artificial species;

Darwin justly mentions the greyhound as being equal to any natural species in the perfect co-ordination of its parts, "all adapted for extreme fleetness and for running down weak prey."[2] Yet it is really an artificial species,[3] formed by long-continued selection under domestication; and there is no reason to suppose that any of the variations which have been selected to form it have been other than gradual and almost imperceptible. Suppose that it has taken five hundred years to form the greyhound out of his wild wolf-like ancestor: this is a mere guess, but it gives the order of the magnitude. Now, we have seen that the past duration of the earth has been about five hundred millions of years, or only one million times greater than this; yet during that period all those changes have taken place by which the highest animal—let us say the elephant—has been developed out of a Protozoon; or, if we admit the hypothesis of a separate ancestor for the vertebrate and for every other fundamentally distinct form, during that period the elephant has been developed out of the earliest and most lowly organized fish. Now, if it takes five hundred years to obtain the present race of greyhounds from a wolf-like ancestor by an accumulation of slow variations, how long would it take to obtain an elephant from a Protozoon, or even from a tadpole-like

produced in perhaps 500 years, by slow variation:

how long would the production

[1] See the article on Darwin's theory, in the *North British Review* for June 1867.

[2] Darwin on Variation under Domestication, vol. ii. p. 221.

[3] This expression will be objected to. But, as I have already stated, I think Darwin, in his Origin of Species, has proved that the distinction between species and variety is only one of degree.

of the highest forms from the lowest require, by the same process?

fish? Ought it not to take much more than a million times as long? I ought perhaps to repeat, that if accuracy of numerical statement here is unattainable, it is also unnecessary; what we have to compare is not the magnitudes themselves, but only the orders of the magnitudes. But the argument, as stated here, is much too favourable to the theory of none but imperceptibly slow variations; for it compares variation under domestication with variation in a state of nature, as if it were equally rapid in both.

Variation is slower among wild than tame races.

And this is not the case: on the contrary, we may say, without much risk of exaggeration, that variability is the rule among domesticated races, but the exception among wild ones. Wild races remain unchanged throughout whole geological ages, though, I have no doubt, they become variable under the influence of changes of habitat, climate, and food; when these changes take place, new varieties and new species, more suitable than the old ones to the new conditions of life, will be formed by the conjoint action of self-adaptation and natural selection. But, so long as variation takes place so slowly as not to produce new races at once (which in Darwin's opinion is always

How selection will act in the wild state.

the case in the wild state), the formation of distinct races in the same habitat will be prevented by intercrossing, and it will be impossible for the processes of change to do more than to modify *the whole race together*, so as to suit the new conditions of life.[1] This will not prevent the action of "natural selection among spontaneous variations," in giving origin to new species, but it must tend greatly to restrict its operation so long as the variations are so small as not to give origin at once to new species, or strongly marked races. The absence of mixtures of race in the wild state will tend to prevent variation, for, as we have seen, pure races are less variable than mixed ones.

[1] If some individuals of a race were so far to change their habits as not to be brought into contact with their kindred,—as, for instance, in the case of becoming nocturnal instead of diurnal,—they would, no doubt, give origin to a new race. But such a change of habit comes to the same thing as a change of country.

Thus there will be less variation in the wild state than in the domestic; and such variations as occur will be much less likely to be kept separate so as to produce modified races. For, as we have seen, the improvement of domestic breeds depends altogether on separation, and would be impossible if the animals were permitted freely to obey their instincts as to breeding. It is true that instinct tends to keep *well-established* breeds distinct, but this is not the case when they are only beginning to diverge.

To recapitulate the foregoing argument:

Geological time is only about a million, or a few million, times as long as the period needed to form what is really a new species by the accumulation of small variations under domestication. Summary.

Variation goes on much less rapidly in the wild than in the domestic state, and favourable variations, when they occur, are much less likely to be so preserved as to produce a modified race. We shall probably be greatly within the mark if we assume that variation is ten times less rapid in the wild state than in the domestic, and that the chance of any favourable variation being so preserved as permanently to modify the race is ten times less. If these numbers are correct, then the efficiency of selection among *small* spontaneous variations in producing new races is one hundred times as great under domestication as in the state of nature. If this is so, then five hundred millions of years of variation and selection under nature are equivalent to only five millions under domestication. And if it takes five hundred years, or anything approaching to that period, to form a race like the greyhound out of a wild dog, it can scarcely be maintained that five millions of years of change at the same rate would suffice to form an elephant out of a fish. Five millions are only ten thousand times five hundred, and the proportion between those two changes is certainly measurable by no such number as ten thousand.

For these reasons, I believe there must have been sudden variations, amounting to the origin of new species all at once; not widely different in any case, perhaps, from the

old ones, but sufficiently different either not to mix with others, or to preserve their distinctness (like the Ancon sheep) in spite of intercrossing.

How far I agree with Darwin.

It may, perhaps, be asked whether I am after all a follower of Darwin or not. This question cannot be answered by a mere yes or no.

I agree with the theory of which Darwin is not the founder but the best known and most original exponent, that all organic species have been descended from one or a few germs.

I believe that Darwin has done most important service to science by pointing out the importance of natural selection among spontaneous variations, as a cause of organic progress. But I do not agree with him that it is almost the only cause.

I believe that geological time is too short to admit of the progress that has taken place, unless variation is a much more rapid process than Darwin admits.

I believe (as stated in the preceding chapter) that the facts of variability being greatest in the lowest organisms, while progress has been most rapid among the higher ones, shows that there is something in organic progress which mere natural selection among spontaneous variations will not account for.

Finally, I believe this something is that Organizing Intelligence which guides the action of the inorganic forces, and forms structures which neither natural selection nor any other unintelligent agency could form.

NOTE.

I FIND that, taking Sir William Thomson as my authority, I have greatly understated the argument of the foregoing chapter. I quote the concluding paragraph of his paper on Geological Time, in the *Transactions of the Geological Society of Glasgow*, vol. iii. :—

"When finally we consider underground temperature, we find ourselves driven to the conclusion that the existing state of things on the earth, life on the earth, all geological history showing continuity of life, must be limited within some such period of past time as *one* hundred million years."

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